Quality Assurance Task Plan
for the
HexSim Model

Updated: 3/18/14

1. TASK DESCRIPTION

1.1 • Overview and Objectives

Wildlife species often use separate resources in distinct locations for shelter and nesting versus for foraging and feeding. Still other resources may be used for rearing and maturing young. Those resources are not static at any one location, but change with plant succession and with imposition of different external disturbances from one year to the next. The ability to accurately predict changes in habitat resources is an essential component of wildlife risk assessments, and has distinct advantages over "what if" assessments based on hypothetical scenarios of habitat change. For example, the linkage of dynamic, process-based habitat and wildlife simulators provides a more realistic and scientifically defensible basis for addressing a number of key questions central to risk assessment, impact analysis, and restoration activities:

1. Given a measurable change in a wildlife population, how much of that change is associated with the effects of a specific anthropogenic stressor (e.g., a regulated chemical) versus climate or other natural stressors that contribute to background variability or "noise" in habitat resources and wildlife mortality and fecundity?
2. What are the direct versus indirect effects of specific chemical or nonchemical stressors on a particular wildlife population, where indirect effects may include disruption of processes controlling ecosystem function (nutrient cycling, primary productivity, etc.)?
3. How can changes in habitat resources and wildlife populations be accurately predicted for conditions for which no historical precedents are available for comparison (e.g., decade to century-scale changes in climate)?

To address these and other questions outlined in EPA's Wildlife Strategy, we will assemble a suite of process-based analytic tools that make it possible to link multiple biotic and abiotic stressors through habitat models to estimate resultant changes in wildlife populations. These models will include a wildlife population simulator (HexSim), and a collection of supporting models that collectively project population changes and habitat conditions forward into time.

1.2 • Products and Timetable

Most of the HexSim development work has already completed. This work was performed under the original version of this QAPP. However, improvements to HexSim will be made throughout the course of the project.

HexSim's suitability as a tool for conducting risk analyses will be derived largely from its eventual ability to link an arbitrary number of life history events separately to different landscape maps. For example, users will be able to impose a survival decision associated with a habitat map, and then follow this with a second survival event linked to a map of pesticide application. This flexibility also will allow us to better model the organism's life history. For instance, two movement events could be employed to cycle individuals between breeding and feeding habitats, with a reproduction event being associated strictly with the breeding landscape. The model will permit as many survival, reproduction, and movement events to be built into the life cycle as is desired, and will continue to allow the suite of landscape maps to change from year to year.

1.3 • Project Personnel

The HexSim model development work is being performed by Dr. Nathan Schumaker, with programming assistance provided by Dr. Allen Brookes.

1.4 • Support Facilities and Services

No specific support facilities are required for this Task. The computing resources necessary for developing the HexSim model are generic and have already been obtained.

2. Model Description

2.1 • Model Overview

The HexSim model was originally designed to predict the response of terrestrial, territorial, vertebrate species to landscape change. Under this Task, the existing model will be modified in such a way that it becomes useful for evaluating population-level response of wildlife species to multiple interacting natural and anthropogenic stressors, especially pesticides.

2.2 • Model Parameters

Inputs to the HexSim model include maps of habitat quality, species-habitat and species-area requirements, and survival and reproductive rates, and estimates of movement ability and behavior. Future versions will permit the user to take the impacts of natural and human-caused disturbances into account, and doing so will require that estimates be made of the changes to vital rates (e.g. individual survival) caused by exposure to a stressor.

HexSim is a population model, but it is individual-based, so population trends are emergent properties that reflect the integration of individual dynamics across landscapes. The spatial extent of a HexSim simulation is specified by the user at run time. The spatial resolution of the data is the pixel (often 30 x 30 meters), but the landscape is resampled by the model to the size of an individual territory or home range. Future versions will make this resampling process more flexible. The time period over which a HexSim simulation extends is specified by the user at run time. The model is data-driven but, in a data-poor environment, can be used to develop hypotheses. HexSim simulations always incorporate demographic stochasticity, but may or may not include environmental stochasticity.

2.3 • Computer Aspects

HexSim source code is based on an earlier model (PATCH) that was originally written in the "C" programming language and ran only on Sun Microsystems computers running the UNIX operating system. The model has since been re-written for Windows using Microsoft Visual C++. Currently, the model is resource-intensive (e.g. it only runs well on a high-end computer), but it is quite portable. It does not require the formal installation process typically associated with Windows applications. Users simply download the executable, and can then run the model. This means that there are no system administration consequences that could result from coding errors on our part.

2.4 • Data Sources and Quality

The goal of this Task is to develop a model capable of simulating the consequences for wildlife populations of multiple interacting stressors. Use of the model to investigate any actual landscape, population, or stressor, is to be conducted as part of other Tasks, or by our Agency collaborators in different Divisions, or Offices. For this reason, there are no data quality issues that pertain to this effort.

2.5 • Data Management

There are no data management issues associated with this Task.

3. MODEL DEVELOPMENT

3.1 • Code Development and Maintenance

The source code for HexSim is maintained and modified using the Microsoft Visual Studio programming environment, and is managed using Subversion. As mentioned above, HexSim is mostly complete, so these tasks are infrequent.

3.2 • Model Documentation

Four parallel approaches to model documentation are being developed:

1. A detailed users guide for HexSim exists, and is constantly updated.
2. A web site has been created for HexSim.
3. A series of worked examples have been developed, and are occasionally updated.
4. A set of tutorials are being developed.

3.3 • Code Verification

Code verification takes place on three levels. At the lowest level, algorithms will be developed that reside within the model code, whose purpose is to perform continuous consistency checks. At an intermediate level, manual examinations will be performed on each principal algorithm. At a higher level, the model as a whole will be tested to make sure its final outputs are consistent with the input data and user expectations.

3.4 • Code Documentation

HexSim is being developed using the latest versions of the Microsoft Visual C++ libraries, and up-to-date programming standards are being applied in this work. Detailed records describing model specifications, algorithm descriptions, internal cause and effect diagrams, source code histories will be developed. In addition, an extensive use of error messages will notify both developers and users of run-time problems and model inconsistencies.

4. Model Application

4.1 • Model Calibration

Due to the design of the HexSim model, there are no calibration issues associated with this task.

4.2 • Model Validation

HexSim is generic life history simulator, and hence the traditional concept of validation is only meaningful when applied to a given model parameterization.

4.3 • Model Uncertainty

The HexSim model is a generic life history simulator. Issues of model uncertainty have bearing on specific parameterizations of the model, but not in the model development itself. In the context of this Task, model uncertainty really becomes a question of code verification and documentation.

Users of the HexSim model must establish how well the model structure and assumptions actually capture the key processes taking place in the ecological system under study. Users must then perform uncertainty analyses to evaluate how variability in their data propagates through to the results they obtain from their HexSim simulations. Finally, users must rely on the integrity of the model source code in order to accept these evaluations of the model's level of uncertainty.

5. Assessment and Oversight

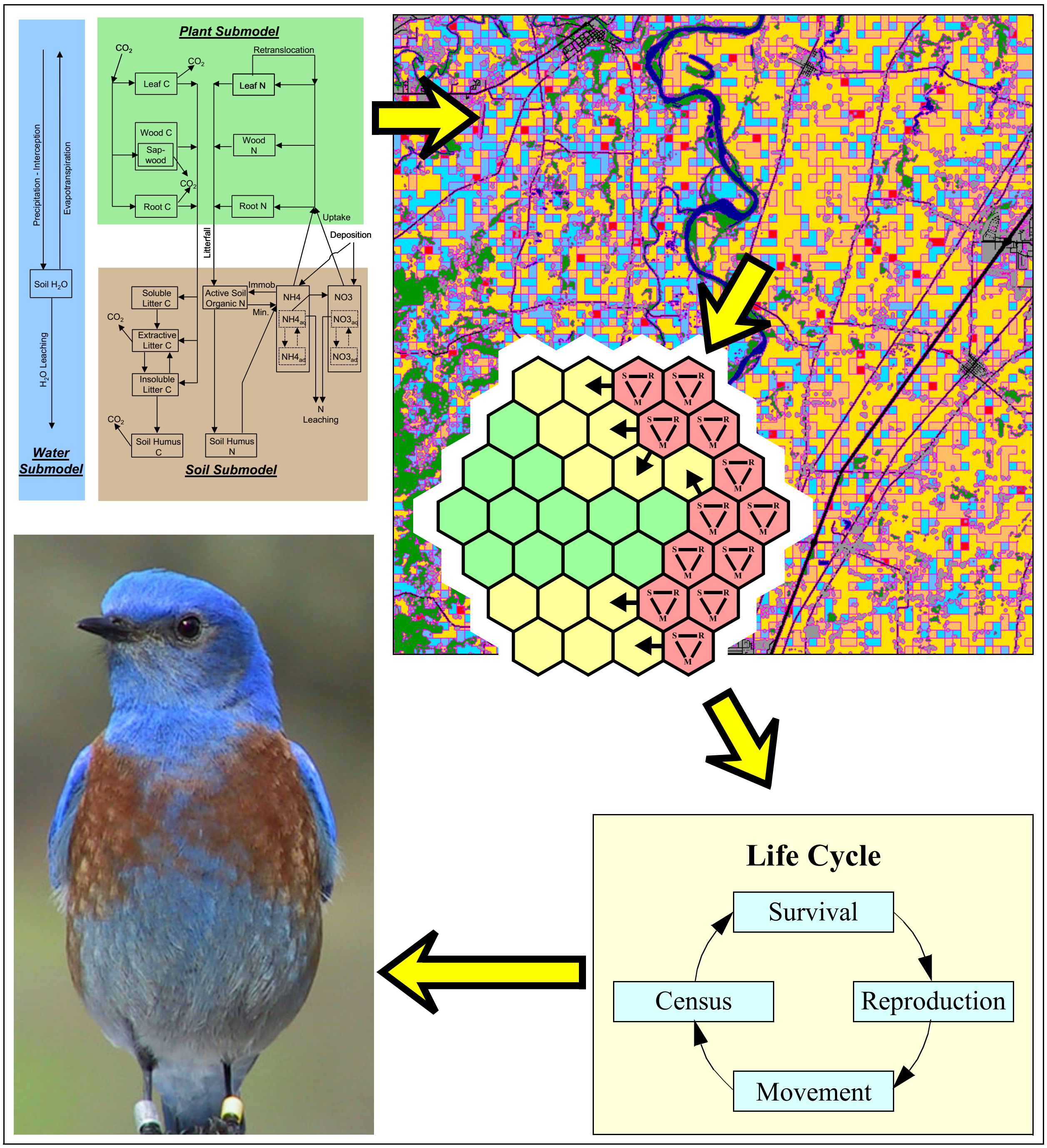
5.1 • Monitoring

Dr. Nathan Schumaker will provide oversight for the HexSim model development task. He will periodically review the status of the model software for integrity and completeness. CSC employees working on the project will develop QA algorithms for specific model procedures.

5.2 • Reporting

The primary form of reporting for this project will be new model releases and new model documentation. Both will be made available through the HexSim model's EPA website. In addition, periodic progress reports (internal documents) will be developed for our EPA clients.

Terrestrial Habitats Project Quality Assurance Plan



Terrestrial Habitats Project

Quality Assurance Project Plan

Version 1.3

Branch Chief	**:**	**Anne Fairbrother**
Project Leaders	**:**	**Nathan H. Schumaker** **Robert B. McKane**
Principal Investigators	**:**	**Peter A. Beedlow** **William E. Hogsett** **E. Henry Lee** **Laura R. Nagy** **Donald L. Phillips** **Allen M. Solomon** **David T. Tingey**
Support Staff	**:**	**Constance Burdick** **Ronald Waschmann**

Terrestrial Habitats Project
Quality Assurance Project Plan

National Health and Environmental Effects Research Laboratory
Western Ecology Division
200 SW 35th Street
Corvallis, Oregon 97333

Version 1.3

Approvals:

Nathan Schumaker, Project Leader — Date: 8/16/05

Bob McKane, Project Leader — Date: 8/16/05

Anne Fairbrother, Risk Characterization Branch Chief — Date: 8/16/05

Robert Ozretich, Quality Assurance Manager — Date: 8/17/05

Distribution List

Version 1.3

Bob Ozretich, QAM

Anne Fairbrother, Branch Chief

Nathan H. Schumaker, Project Leader

Robert B. McKane, Project Leader

Project Federal Staff

Project Contract Staff

Other Project Staff, Students, and Cooperators

Table of Contents

1. INTRODUCTION

EPA's ecological research program seeks to assess, improve, and restore the integrity and sustainability of ecosystems over time. Research in this area will develop models to understand, predict, and assess the response of ecosystems to multiple interacting stressors at multiple spatial and temporal scales. These models will support the Agency's risk assessors in their efforts to make more sustainable management decisions, and ORD has committed to deliver this new generation of analytic tools by 2008. To guide this work, NHEERL is developing an Implementation Plan for research to address wildlife population endpoints as a function of terrestrial habitat quantity, quality and distribution, and as affected by multiple stressors across many temporal and spatial scales. The plan calls for WED scientists to take the lead in terrestrial habitat and wildlife population modeling while collaborating with the other Ecological Research Divisions to address the overall Agency problems.

This research project will respond to Program Office needs in three specific problem areas. First, the Scientific Advisory Panel for the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA) specifically recommended that the Office of Pesticide Programs conduct probabilistic assessments of risks to ecosystems associated with pesticide use. Second, the Office of Prevention, Pesticides, and Toxic Substances needs efficient methods, including models, to review, register, and regulate thousands of chemicals in a timely fashion. Finally, the Office of Water has a need for improved methodology for probabilistic assessment of the impact of habitat alteration on aquatic-dependant terrestrial wildlife, and the Office of Solid Waste and Emergency Response has similar needs for assessing contaminant effects in terrestrial systems.

There are common threads to the Agency problems we have identified. All three can be addressed using models that relate stressor exposure to effects on wildlife populations through effects on plant communities and ecosystems, and all three involve extrapolation in biological scale, space, and time. Thus, three over-arching questions will guide our research:

1. Do changes in habitat quantity, quality, and distribution explain quantitative changes in wildlife populations?
2. What are the characteristics of wildlife habitat that are susceptible to stressors, resulting from changes in diversity, foodweb structure, and ecosystem function?
3. What is the likelihood that stressor exposure will affect non-target animal and plant species over variable spatial and temporal scales?

1.1 • Goals

The Terrestrial Habitats project will develop tools and databases to meet the needs of our Program Office clients. We will develop an enhanced version of the PATCH wildlife population simulator and demonstrate its application to pesticide risk assessments in real or hypothetical agroecosystems through two case studies. A database of wildlife demographic information will be populated to support the input parameter needs of the model. Together, these studies will capture effects of patterns of habitat structure and human activity on wildlife population size and distribution. Because habitat is a dynamic condition in real-world environments, our approach includes the development of a set of linked models that can simulate long-term changes in plant community dynamics as a result of natural or anthropogenic stressors (e.g., fire, climate change, nutrient inputs, etc.). These models include a biogeochemistry (GEM) and tree growth (TREGRO) model, as well as a forest community model (FORCLIM or ZELIG). Wildlife population changes that may result from habitat alterations can then be predicted by overlaying PATCH on these simulated, dynamic landscapes.

This research will produce a new methodology for terrestrial wildlife risk assessments that is spatially explicit and designed for use in real settings. It will track conditions in ecosystems of concern over time frames that are ecologically relevant, and will provide the tools for assessing impacts on wildlife populations from multiple interacting natural or anthropogenic disturbances. The outputs will be computer-generated visualizations of predicted changes that can provide Risk Managers with real tools for use in environmental decision-making.

2. Project QA Organization and Responsibilities

The following organizational structure for QA/QC issues was designed to facilitate meeting the QA goals within the project and to facilitate communication between management and the project personnel. Six essential QA/QC elements (listed below) are addressed within the organizational structure:

1. QA/QC responsibilities
2. Research responsibilities
3. Communication
4. Document Control
6. Quality Assurance Task Plans and Standard Operating Procedures

Our experimental procedures are described through our QATPs and associated. Collectively, the QAPP provides a framework for conducting both the scientific tasks and QA/QC procedures that make up the Terrestrial Habitats Project.

2.1 • QA/QC Responsibilities

WED management and research staff share responsibility for implementing the Laboratory's QA policies, and they are accountable for those aspects of QA/QC associated with their work areas. The QA Responsibilities in this Quality Assurance Project Plan (QAPP) were derived from Section 1.0 of the US EPA, NHEERL, Western Ecology Division Quality Management Plan (U.S. EPA 1995). Our Project's QA/QC organizational structure is as follows:

Branch Chief

The Project is managed within the Risk Characterization. The Branch Chief is responsible for all projects within the Branch and for ensuring that all technical outputs meet the quality requirements of the Laboratory and Agency. The Branch Chief also is the direct line manager to the Project Leaders, and can apply Branch resources to resolve QA issues. The Branch Chief's key QA responsibilities are to:

- Review and evaluate work on QA implementation and progress.
- Review and evaluate the quality of outputs generated by each project.
- Review and evaluate audit and performance evaluation reports.

Project Leader

The Project Leader is management's principle contact with the Project, and is responsible for the performance and coordination of the Project. The Project Leader determines quality criteria based on the intended use of the research products, and communicates these criteria to the Project participants. The Project Leader's key QA responsibilities are to:

- Coordinate writing of the QA Project Plan (QAPP).
- Negotiate quality requirements with Project participants.
- Ensure that QATPs are developed for each task, reviewed and approved.
- Ensure that SOPs are developed, and review and approve SOPs.
- Review Project QA outputs.
- Allocate project resources to resolve QA issues.
- Review QA data annually (Performance and System Audits).
- Prepare annual QA reports for submission to Branch Chief.
- Maintain original, approved, copies of all SOPs, QATPs and the QAPP and manage the Project's document control policies.

Principal Investigator

Principal Investigators are responsible for carrying out specific portions of the Project Research Tasks, and insuring the quality of the results that are subsequently generated. The PI's key QA/QC responsibilities are to:

- Participate in the preparation of the QAPP.
- Negotiate quality requirements with the Project Leader.
- Write the QATPs for tasks where they have primary responsibility.
- Write the SOPs necessary for those tasks.
- Train Project participants to perform and evaluate QC measurements.
- Train Project participants to perform and document preventative maintenance.
- Report problems and corrective actions to the Project Leader.
- Verify that QC activities are performed, and that data quality meet the requirements specified in the QAPP.
- Review laboratory notebooks and other primary data sources.
- Review QA data annually (Performance and System Audits).
- Make data quality determinations based on the QC data collected, and document the determinations.
- Insure that required corrective actions are implemented and documented.
- Archive QA/QC data.
- Assist in the Laboratory's QA audit by working through the Project Leader.

Project Scientists

Project Scientists work directly on the Project's research and QA/QC procedures by interacting frequently with other Project participants. The Project Scientist's key QA/QC responsibilities are to:

- Assist in writing and implementing SOPs.
- Perform and evaluate QC measurements.
- Perform and document preventative maintenance.
- Report problems and corrective actions to the PI.
- Implement corrective actions.

Personnel

The personnel performing each of these duties are identified in Table 1, below.

2.2 • Research Responsibilities

To insure that all facets of the Project are on schedule, and that important parts of the Project are not omitted, individual PIs are assigned specific Research Tasks (Table 2). Each of these tasks is assigned a QA Task Plan (QATP), and these are included as appendices to this document. The SOPs to be followed, while performing the research activities described in a specific task, are described in the QATP. The QATPs are included as appendices to this document.

2.3 • Communication

The Project PIs will meet at least once a month to:

Table 1. QA/QC Duties

Branch Chief	Dr. Anne Fairbrother	
Project Leader	Dr. Nathan Schumaker	
Principal Investigators	Dr. Nathan Schumaker	PATCH Model Development Agricultural Landscapes Case Study
	Dr. Robert McKane	GEM Model Development Model Linkages and Visualization Forested Landscapes Case Study
	Dr. Allen Solomon	FORCLIM Model Development
Project Tasks	PATCH Model Development	Dr. Nathan Schumaker
	GEM and NESIS Model Development	Dr. Robert McKane
	FORCLIM Model Development	Dr. Allen Solomon
	Model Linkages and Visualization	Dr. Robert McKane Dr. Allen Solomon
	Agricultural Landscapes Case Study	Dr. Laura Nagy Dr. Donald Phillips Dr. Nathan Schumaker
	Forested Landscapes Case Study	Dr. Peter Beedlow Constance Burdick Dr. William Hogsett Dr. Henry Lee Dr. Robert McKane Dr. Donald Phillips Dr. Allen Solomon Dr. David Tingey Ronald Waschmann

- Coordinate sampling and various experimental activities.
- Exchange data and information about the various tasks.
- Share scientific information.
- Refine and/or modify the Research Plan, the QAPP, QATPs and SOPs.

The PIs and other Project participants will meet on an "as needed" basis to:

- Coordinate experimental activities.
- Exchange information.
- Resolve problems.

2.4 • Document Control

It is important that all Project participants have access to the QAPP, QATPs, and SOPs. To insure this is done, a document control procedure will be implemented. The Project Leader will be responsible for maintaining the original signed copies of the QAPP and approved QATPs and SOPs, and ensuring distribution of copies of these documents to Project participants as needed. In addition, copies of the approved documents will be converted into PDF files and made available to Project participants on the local network (*\\Nabu\Terrestrial Habitat\QA QC*). The project leader will ensure that records are kept with proper version numbers of the approved QAPP and each approved QATP and SOP. If the QAPP, QATP or a SOP is revised, the Project Leader will update the network copy, and advise all project participants that this change has been made. Project participants will always refer to the network repository (*\\Nabu\Terrestrial Habitat\QA QC*) for the most recent versions, and shall not maintain their own copy of the QAPP. This procedure will insure that out-dated copies of these documents are not in use.

2.5 • Quality Assurance Task Plans and Standard Operating Procedures

In addition to the Project's Research Plan, QATPs provide the basic experimental design for each task listed in Table 2, and list the essential SOPs needed for data collection. SOPs provide the detailed information to conduct the individual research and QA/QC measurements. Our SOPs are designed to meet the following four specific objectives:

Table 2. Research Tasks

Number	Title	Lead PI
1	Develop, calibrate, and test PATCH model.	Schumaker
2	Develop, calibrate, and test GEM model.	McKane
3	Develop, calibrate, and test FORCLIM model.	Solomon
4	Assemble model linkages and visualization tools.	McKane
5	Conduct agricultural landscapes case study.	Schumaker
6	Conduct managed forest landscape case study.	McKane

1. Provide sufficient information for individuals to conduct the research.
2. Provide a written record of how the data were collected.
3. Present the QA/QC needs in a format that is useful for the Project participants.
4. Provide a standardized format for reporting data.

Standard Operating Procedures will be either employed or developed for all environmental measurements required to fulfill the Research Tasks shown in Table 2. Additional procedures may be developed as tasks are implemented. Given the central role of SOPs in the Project's QA program, much of the detailed QA/QC information will be contained in the approved SOPs. Additional details and theoretical underpinnings for the Research Tasks are contained in the Project's Research Plan.

3. Contents of Quality Assurance Task Plans

Each task listed in Table 2 shall have a QATP that discusses all of the QA/QC issues pertaining to the effort. Our tasks involve either model development, or the implementation of case studies, and the QATP structure for these two types of studies differ. Our QATPs have all been developed using the format indicated below.

Task Description

<u>Overview and Objectives</u> This section provides an overview of the Task, illustrates its connection to the Research Plan, and its objectives or principal hypotheses.

<u>Products and Timetable</u> This section describes the APMs, or other products associated with the Task, and the timetable under which they will be developed.

<u>Project Personnel</u> This section lists the personnel involved in conducting the Task.

<u>Support Facilities and Services</u> This section describes the range of facilities and services that will be required to complete the Task. These may be Federal or Non-Federal, and local or remote.

Methodology (case studies only)

<u>Experimental Design</u> Each Quality Assurance Task Plan will describe the experimental design to be used in meeting the stated objectives. This section should include specific information on study sites and locations as well as sampling design. Details on the timing, frequency and pattern of data collection to meet the Task objectives should be included.

<u>Measurements and Data Acquisition</u> Data quality objectives (DQOs) will be established to insure that appropriate data are collected with the right accuracy, precision and frequency. The Project Leader will work with individual PIs to develop the DQOs for various measurements to insure that the Task goals and met, and are consistent with those of other similar Tasks, when appropriate. The specific DQOs for each measurement are contained within the individual SOPs.

Model Description (model development only)

Model Overview This section introduces the model and discusses its relevance in regards to the Task goals.

Model Parameters This section describes the various input parameters that are required to run the model in question.

Computer Aspects This section describes the type of computer platform, and hardware and software requirements necessary to run the model in question.

Data Sources and Quality This section describes the type and quality of the input data used to drive the model in question.

Data Management This section discusses the strategies to be implemented for short and long-term data storage and retrieval.

Model Development (model development only)

Code Development and Maintenance This section describes the personnel and procedures involved in developing and maintaining the model source code.

Model Documentation This section describes the model documentation that either exists or will be produced as part of the Task.

Code Verification This section describes the procedures that will be used to verify code quality, including identification of conceptual errors (errors in model conception), implementation errors (errors in model design), and coding errors (errors in model implementation).

Code Documentation This section illustrates the approach that will be used to document the model source code.

Model Application (model development only)

Model Calibration This section describes the process that will be used to calibrate the model so that its outputs match the tuning standards being used.

Model Validation This section describes the approach that will be used to verify the plausibility of the model outputs, to the extent this is possible. Statements about a model's validity are limited by the certainty that can be assigned to its input parameters, and by the accuracy of any assumptions around which it is designed.

Model Uncertainty This section describes the approach that will be used to address uncertainty inherent in the model.

Quality Control and Assurance (case studies only)

Equipment and SOPs Each QATP shall include a list of equipment used to collect data for the Task objectives, and the associated SOPs for that equipment.

Quality Control This section illustrates how data quality are controlled for a given experimental design.

Quality Assurance This section illustrates how data quality are assured for a given experimental design.

Data Management This section documents how the data for the particular task will be managed and stored.

Assessment and Oversight

Monitoring This section will list the personnel involved in monitoring the use, calibration, and verification of the model and modeling products in question.

Reporting This section will discuss format and audience for the reports that will be generated while conducting the Task in question.

4. Content of Individual SOPS

Each SOP shall contain the following QA/QC information.

Objective Statement Each SOP shall contain an objective statement that includes the data quality objectives (DQOs) for that particular measurement.

List of Equipment This section provides a list of equipment necessary for collecting the data while meeting the DQOs.

Sample Procedures and Custody This section describes the sampling and storage procedures necessary to meet the DQOs.

Analytical procedures This section lists the details of sampling procedures.

Quality Assurance/Quality Control This section explains how data quality are assured and controlled. For example, for measurement methods and device, the section shall list appropriate calibration procedures. For analytical instruments, this section will contain the number of standards used, their composition, and concentration.

Preventative Maintenance and Corrective Action This section specifies the frequency of required maintenance activities, and corrective actions needed to meet the DQO.

Data reduction, validation and reporting This section traces the data collection from the field or raw data sheets (include reporting units or data format used) through computer file entry and archiving.

5. Performance and System Audits

An overall performance audit for all Project measurement systems will be conducted once per year by the Project Leader and Principal Investigators. This audit will examine each measurement system identified in the individual SOPs. This yearly overall performance audit will form the basis for the Project's annual quality assurance report to management, which in turn contributes to the WED QA Program audits that occur once every two years. Responsibility for ensuring the realization of the annual overall performance audits, and the WED QA Program audit lies with the Project Leader.

6. Quality Assurance Reports to Management

Summaries of the reports on the yearly overall performance audits will be presented annually to the Project Leader and Branch Chief for review and evaluation. The summaries will include the items specified in the WED Quality Management Plan, plus any other findings contained in the overall performance audit reports.

2003	2004	2005	2006	2007	2008	2009	2010
	APM 57	APM D APM A	APM C	APM E	APM I APM F	APM G	APM H APM J
Complete PATCH I	Initiate PATCH II	Incorporate Chemical Stressors		Generalize Life History Module		Add Community Dynamics Module	
Iowa - Pennsylvania Agricultural Landscapes Research Effort Willamette Valley Agriculture and Pesticides Research Effort							
Develop Linked Ecosystem / Plant / Community Models							
Stand-Level Predictions							
	Landscape-Level Predictions						
		Merge with PATCH					

Figure 1 The Project timeline. APM numbering corresponds to Table 3.

7. TIMELINE

The timeline along which the Terrestrial Habitats Project will be developed (Figure 1) is derived principally from the APMs associated with the various tasks from which it is comprised (Table 3).

Table 3. APMs Assigned to the Terrestrial Habitats Project

GOAL 4 (Ecological Research) ▪ LTG 2 (Diagnosis)			
APG	*Deliver to program and regional offices a computerized GIS for conducting spatially explicit ecological risk assessments.* **(2004)**		
	APM	**Date**	**Contact**
57	Deliver Windows version of PATCH model with documentation and example analysis. **(Deliverable: Copy of model delivered to program office)**	2004	Schumaker

GOAL 4 (Ecological Research) ▪ LTG 2 (Diagnosis)			
APG 56	*Deliver to Program Offices and Regional Offices data and models for understanding national distribution of habitat and natural populations for spatially explicit ecological risk assessments.* **(2005)**		
	APM	**Date**	**Contact**
A	Report on vegetation growth and community structure models that link to habitat based population models for predicting stressor effects on wildlife habitat. **(Deliverable: EPA report)**	9/30/05	McKane

GOAL 4 (Ecological Research) ▪ LTG 2 (Diagnosis)			
APG	*Deliver to Program Offices and Regional Offices life history and other biological data for estimating the effects of national variation and habitat disturbance on the variability of natural populations.* **(2005)**		
	APM	**Date**	**Contact**
B	Development of a species demographic and habitat requirement database structure for use in parameterizing population models that incorporate natural variation and habitat disturbance. **(Deliverable: EPA report)**	9/30/05	Schumaker
GOAL 4 (Safe Communities) ▪ LTG 2 (Probabilistic Risk Assessment)			
APG	*Provide computerized framework for characterizing in a spatially explicit manner risks from toxic chemicals to populations of aquatic life and terrestrial wildlife capable of integration with OPP databases.* **(2008)**		
	APM	**Date**	**Contact**

Table 3. APMs Assigned to the Terrestrial Habitats Project

C	Delivery of PATCH version with interfaces to distributed databases and population models. **(Deliverable: PATCH model)**	2006	Schumaker

GOAL 4 (Ecological Research) ▪ LTG 2 (Diagnosis)			
APG	*Deliver to program and regional offices an updated GIS with databases and models for conducting spatially explicit ecological risk assessments.* **(2010)**		
	APM	**Date**	**Contact**
D	Provide PATCH demonstration model as a platform for assessing the cumulative risks to selected bird species from habitat alteration and chemical stressors. **(Deliverable: Copy of PATCH model and EPA report)**	9/30/05	Schumaker
E	Provide a generally applicable, linked GIS-biogeochemical hydrologic model for predicting landscape scale changes in terrestrial habitats in response to stress. **(Deliverable: Copies of relevant models and EPA report)**	2007	McKane
F	Deliver revised PATCH II model for Windows with generalized life history module and general stressor module. **(Deliverable: Copy of PATCH delivered to program office)**	2008	Schumaker
G	Provide user interface and visualization programs for PATCH and habitat models. **(Deliverable: Visualization software plus documentation)**	2009	McKane
H	Report on the calibration of PATCH and GIS-biogeochemical based habitat models for the Great Plains regions **(Deliverable: EPA report)**	2010	Schumaker
GOAL 4 (Ecological Research) ▪ LTG 2 (Diagnosis)			
APG	*Provide methodology and demonstrate its applicability for predicting cumulative impacts of multiple stressors on interacting wildlife populations and their habitats.* **(2015)**		
	APM	**Date**	**Contact**

Table 3. APMs Assigned to the Terrestrial Habitats Project

I	Report on the efficacy of plant and animal community ecosystem modeling approaches to assess risk from multiple stressors. **(Deliverable: EPA report)**	2008	Schumaker
J	Provide an expanded version of PATCH model capable of assessing interacting wildlife populations in dynamic communities. **(Deliverable: PATCH model)**	2010	Schumaker
K	Provide databases in support of models for predicting cumulative risks of multiple stressors in a range of ecological communities. **(Deliverable: Copies of databases plus documentation)**	2012	Schumaker
L	Demonstrate risk assessment approaches to evaluate cumulative impacts of multiple stressors in a range of ecological communities. **(Deliverable: EPA report)**	2014	Schumaker
M	Provide a synthesis of approaches to predict cumulative impacts of multiple stressors on interacting wildlife populations and their habitats. **(Deliverable: EPA report plus relevant models and databases)**	2015	Schumaker

Appendix 1

Quality Assurance Task Plan
for the
PATCH Model Development Project

Version 1.3 *August 17, 2005*

1. TASK DESCRIPTION

1.1 • Overview and Objectives

Wildlife species often use separate resources in distinct locations for shelter and nesting versus for foraging and feeding. Still other resources may be used for rearing and maturing young. Those resources are not static at any one location, but change with plant succession and with imposition of different external disturbances from one year to the next. The ability to accurately predict changes in habitat resources is an essential component of wildlife risk assessments, and has distinct advantages over "what if" assessments based on hypothetical scenarios of habitat change. For example, the linkage of dynamic, process-based habitat and wildlife simulators provides a more realistic and scientifically defensible basis for addressing a number of key questions central to risk assessment, impact analysis, and restoration activities:

1. Given a measurable change in a wildlife population, how much of that change is associated with the effects of a specific anthropogenic stressor (e.g., a regulated chemical) versus climate or other natural stressors that contribute to background variability or "noise" in habitat resources and wildlife mortality and fecundity?
2. What are the direct versus indirect effects of specific chemical or nonchemical stressors on a particular wildlife population, where indirect effects may include disruption of processes controlling ecosystem function (nutrient cycling, primary productivity, etc.)?
3. How can changes in habitat resources and wildlife populations be accurately predicted for conditions for which no historical precedents are available for comparison (e.g., decade to century-scale changes in climate)?

To address these and other questions outlined in EPA's Wildlife Strategy, we will assemble a suite of process-based analytic tools that make it possible to link multiple biotic and abiotic stressors through habitat models to estimate resultant changes in wildlife populations. These models will include a wildlife population simulator (PATCH), and a collection of supporting models that collectively project population changes and habitat conditions forward into time.

The wildlife model we intend to use in this project is called PATCH (Program to Assist in Tracking Critical Habitat; Schumaker, 1998). PATCH is a spatially-explicit, individual based life history simulator that incorporates geographical information system (GIS) representations of landscapes. There are several reasons for our selection. PATCH's attention to spatial detail allows us to examine the consequences of complex spatial and temporal modifications to habitat structure and quality. Additionally, the model's design makes it ideal for exploring the cumulative impacts of multiple stressors. PATCH also has been used to examine the influence of projected future habitat conditions on a suite of wildlife species in Oregon's Willamette Valley (Schumaker *in press*), and to assess the ability of a variety of wildlife species to persist in landscapes experiencing multiple types of habitat modifications (Schumaker 1996, Carroll et. al. 2001, Richards et. al. 2002, Carroll et. al. 2003a, Carroll et. al. 2003b, Rustigian et. al. 2003, Calkin et. al. *in press*, Carroll et. al. *in press*, Lawler and Schumaker *in press*, Nalle et. al. *in press*).

1.2 • Products and Timetable

PATCH is an existing model that was developed as part of the EPA's Willamette Valley Ecological Research Consortium. Requirements of the Terrestrial Habitats Project will necessitate that a number of improvements be made to the model. Future versions of PATCH model will couple life history parameters associated with a wildlife species to habitat maps and an arbitrary number of interacting stressors. The principal results of the simulations will be quantitative projections of population trends and distribution. Standard model outputs will include population size and structure, estimates of population viability, and mean movement distances. Results that are more unique to PATCH will include maps of habitat quality, population density, birth and death rates, and immigration and emigration rates, all of which change through time. We will also be able to examine the likely impact of changes to the severity, distribution, or timing of habitat alterations, chemical applications, or other stressors. The PATCH model design will permit these types of analyses to be conducted using actual landscapes and realistic suites of natural and anthropogenic stressors.

Improvements to PATCH will be made throughout the course of the Terrestrial Habitats Project. We will generalize the animal's use of space to accommodate irregularly shaped territories and the grouping of individuals into flocks, colonies, packs or herds. We will allow users to define the organism's life history at run-time by building up the life cycle from a suite of survival, reproduction, and movement events. Newer versions will allow each survival, reproduction, or movement event to be linked to a specific (and possibly unique) landscape map. Density dependence will be incorporated by allowing individuals to adjust their vital rates based on the local number of conspecifics. Finally, in future versions of the model, users will have the option to follow males in addition to females.

PATCH's suitability as a tool for conducting risk analyses will be derived largely from its eventual ability to link an arbitrary number of life history events separately to different landscape maps. For example, users will be able to impose a survival decision associated with a habitat map, and then follow this with a second survival event linked to a map of pesticide application. This flexibility also will allow us to better model the organism's life history. For instance, two movement events could be employed to cycle individuals between breeding and feeding habitats, with a reproduction event being associated strictly with the breeding landscape. The model will permit as many survival, reproduction, and movement events to be built into the life cycle as is desired, and will continue to allow the suite of landscape maps to change from year to year.

The APMs associated with this Task are listed in the Project's QAPP, in Table 3. A timeline for this Task is illustrated in the Project's QAPP, in Figure 1.

1.3 • Project Personnel

The PATCH model development work is being performed by Dr. Nathan Schumaker, with programming assistance provided by CSC. Dr. Schumaker will oversee all aspects of the PATCH model development work.

1.4 • Support Facilities and Services

No specific support facilities are required for this Task. The computing resources necessary for developing the PATCH model are generic and have already been obtained.

2. MODEL DESCRIPTION

2.1 • Model Overview

The PATCH model was originally designed to predict the response of terrestrial, territorial, vertebrate species to landscape change. Under this Task, the existing model will be modified in such a way that it becomes useful for evaluating population-level response of wildlife species to multiple interacting natural and anthropogenic stressors, especially pesticides.

2.2 • Model Parameters

Inputs to the PATCH model include maps of habitat quality, species-habitat and species-area requirements, and survival and reproductive rates, and estimates of movement ability and behavior. Future versions will permit the user to take the impacts of natural and human-caused disturbances into account, and doing so will require that estimates be made of the changes to vital rates (e.g. individual survival) caused by exposure to a stressor.

PATCH is a population model, but it is individual-based, so population trends are emergent properties that reflect the integration of individual dynamics across landscapes. The spatial extent of a PATCH simulation is specified by the user at run time. The spatial resolution of the data is the pixel (often 30 x 30 meters), but the landscape is resampled by the model to the size of an individual territory or home range. Future versions will make this resampling process more flexible. The time period over which a PATCH simulation extends is specified by the user at run time. The model is data-driven but, in a data-poor environment, can be used to develop hypotheses. PATCH simulations always incorporate demographic stochasticity, but may or may not include environmental stochasticity.

2.3 • Computer Aspects

PATCH was originally written in the "C" programming language and ran only on Sun Microsystems computers running the UNIX operating system. The model has since been re-written for Windows using Microsoft Visual C++. Currently, the model is resource-intensive (e.g. it only runs well on a high-end computer), but it is quite portable. It does not require the formal installation process typically associated with Windows applications. Users simply download the executable, and can then run the model. This means that there are no system administration consequences that could result from coding errors on our part.

2.4 • Data Sources and Quality

The goal of this Task is to develop a model capable of simulating the consequences for wildlife populations of multiple interacting stressors. Use of the model to investigate any actual landscape, population, or stressor, is to be conducted as part of other Tasks, or by our Agency collaborators in different Divisions, or Offices. For this reason, there are no data quality issues that pertain to this effort.

2.5 • Data Management

There are no data management issues associated with this Task.

3. Model Development

3.1 • Code Development and Maintenance

Copies of Microsoft Source-Safe (part of the Visual C++ programming environment) have been obtained for this project. Source-Safe implements a versioning procedure and creates an electronic history of the code development process. Use of the Source-Safe package ensures a record is kept of all changes to the model source code.

The source code for PATCH is a very large and complex, but the model as a whole is conceptually simple, making validation a manageable process. At its core, PATCH simply distributes a large number of population projection matrices across a complex landscape. Projection matrices are just about the simplest ecological model possible, and are also amongst the most common. Individual matrices control the fate of subpopulations, and subpopulations are linked through dispersal. The complexity in PATCH, particularly in future versions of the model, derives from the fact that multiple spatially-distributed stressors can each effect the projection matrices (and hence subpopulations) across unique portions (or all) of the landscape being modeled. These stressors include habitat quality, and the interactions between landscape, population, and stressors can produce complex results that might not be obtained from a non-spatial modeling approach. On the other hand, this “bottom up” approach lends itself to careful scrutiny. For example, the landscape structure or action of a stressor can be simplified to the extent that the model results become easy to predict mathematically. A series of validation exercises will be used to test the model structure for coding errors. This manual approach to QA is coupled with a number of automated consistency tests that are conducted internally by the model.

Model output includes various measures of population size, and maps of habitat occupancy, immigration and emigration rates, etc. These outputs facilitate the QA process. For example, in the absence of landscape structure or stressors, simulated populations should exhibit exponential growth or decline equivalent to that mandated by the population projection matrix supplied by the user.

3.2 • Model Documentation

Four parallel approaches to model documentation are being developed:

1. A detailed users guide was published for an earlier version of PATCH. A new version of this document will be produced when the model development work slows down.
2. A web site has been created and is being used to introduce potential users to the model. The web site will present some model background, describe its data requirements, and illustrate some of its outputs.
3. A series of worked examples are being developed, and will be distributed via the web site.
4. A set of graphical tutorials are being designed to introduce users to the model and explain its internal structure. These will be constructed using the ViewletBuilder program developed by Qarbon, Inc.

Detailed descriptions of the model's internal workings, such as underlying equations, the order of operations, etc. will be documented in the detailed user's guide. The other instructions needed by users will be included in different forms amongst all of the documentation described above. This will help ensure that its accessible to the widest audience possible.

3.3 • Code Verification

Code verification is taking place on three levels. At the lowest level, algorithms will be developed that reside within the model code, whose purpose is to perform continuous consistency checks. At an intermediate level, manual examinations will be performed on each principal algorithm. At a higher level, the model as a whole will be tested to make sure its final outputs are consistent with the input data and user expectations.

3.4 • Code Documentation

PATCH is being developed using the latest versions of the Microsoft Visual C++ libraries, and up-to-date programming standards are being applied in this work. Detailed records describing model specifications, algorithm descriptions, internal cause and effect diagrams, source code histories will be developed. In addition, an extensive use of error messages will notify both developers and users of run-time problems and model inconsistencies.

4. Model Application

4.1 • Model Calibration

Due to the design of the PATCH model, there are no calibration issues associated with this task.

4.2 • Model Validation

PATCH is generic life history simulator, and hence the traditional concept of validation is only meaningful when applied to a given model parameterization. The model itself is a logical but simplistic approximation to the real world. Future versions of PATCH will allow additional complexity (and hopefully realism), but will not prevent simpler analyses from being conducted. Thus, in reference to this Task, model validation is reduced code verification and code documentation, which are addressed above.

The QAPP, of which this QATP is a part, includes tasks that involve parameterization and execution of the PATCH model. The QATPs associated with these tasks will address the issue of model validation in a more traditional way. Because the PATCH model is being developed specifically for the Terrestrial Habitats Research Project, there are no QA issues pertaining to model restrictions or validity, such as would arise if an existing model was being used to address a research question for which it was not originally designed.

4.3 • Model Uncertainty

The PATCH model is a generic life history simulator. Issues of model uncertainty have bearing on specific parameterizations of the model, but not in the model development itself. In the context of this Task, model uncertainty really becomes a question of code verification and documentation. Users of the PATCH model must establish how well the model structure and assumptions actually capture the key processes taking place in the ecological system under study. Users must then perform uncertainty analyses to evaluate how variability in their data propagates through to the results they obtain from their PATCH simulations. Finally, users must rely on the integrity of the model source code in order to accept these evaluations of the model's level of uncertainty.

5. Assessment and Oversight

5.1 • Monitoring

Dr. Nathan Schumaker will provide oversight for the PATCH model development task. He will periodically review the status of the model software for integrity and completeness. CSC employees working on the project will develop QA algorithms for specific model procedures.

5.2 • Reporting

The primary form of reporting for this project will be new model releases and new model documentation. Both will be made available through the PATCH model's EPA website. In addition, periodic progress reports (internal documents) will be developed for our EPA clients.

6. References

Calkin, D., C. A. Montgomery, N. H. Schumaker, S. Polasky, J. L. Arthur, and D. J. Nalle. Developing a production possibility set of wildlife species persistence and timber harvest value using simulated annealing. *In Press*. Canadian Journal of Forest Research.

Carroll, C., R. F. Noss, N. H. Schumaker, and P. C. Paquet. 2001. Is the return of the wolf, wolverine, and grizzly bear to Oregon and California biologically feasible?. In D. Maehr, R. Noss, and J. Larkin, eds. Large mammal restoration: ecological and sociological challenges in the 21st century. Island Press, Washington, DC.

Carroll, C., M. K. Phillips, N. H. Schumaker, and D. W. Smith. 2003. Impacts of landscape change on wolf restoration success: Planning a reintroduction program using static and dynamic spatial models. Conservation Biology 17:536-548.

Carroll, C., R. F. Noss, P. C. Paquet, and N. H. Schumaker. 2003. Use of population viability analysis and reserve selection algorithms in regional conservation plans. Ecological Applications 13:1773-1789.

Carroll, C. R. F. Noss, P. C. Paquet, and N. H. Schumaker. Extinction debt of protected areas in developing landscapes. *In Press*: Conservation Biology.

Lawler, J. J., and N. H. Schumaker. Evaluating habitat as a surrogate for population viability using a spatially explicit population model. *In Press*: Environmental Monitoring and Assessment.

Nalle, D. J., C. A. Montgomery, J. L. Arthur, S. Polasky, and N. H. Schumaker. Modeling joint production of wildlife and timber in forests. *In Press*. Journal of Environmental Economics and Management.

Richards, W. H., W. O. Wallin, and N. H. Schumaker. 2002. An analysis of late-seral forest connectivity in western Oregon. Conservation Biology 16:1409-1421.

Rustigian, H. L., M. V. Santelmann, and N. H. Schumaker. 2003. Assessing the potential impacts of alternative landscape designs on amphibian population dynamics. Landscape Ecology 18:65-81.

Schumaker, N. H. 1996. Using landscape indices to predict habitat connectivity. Ecology 77:1210-1225.

Schumaker, N. H. 1998. A Users Guide to the PATCH Model. EPA/600/R-98/135. U.S. Environmental Protection Agency, Environmental Research Laboratory, Corvallis, Oregon.

Schumaker, N. H., T. Ernst, D. White, J. Baker, and P. Haggerty. Projecting wildlife responses to alternative future landscapes in Oregon's Willamette Valley. *In press*: Ecological Applications.

Appendix 2

Quality Assurance Task Plan for the GEM Model Development Project

Version 1.3 *August 17, 2005*

1. TASK DESCRIPTION

1.1 • Overview and Objectives

The purpose of this task is to develop and apply a terrestrial biogeochemistry model (MBL-GEM) to address the following research question: How do multiple, interacting stressors control changes in wildlife habitat and populations across large spatial and temporal scales, i.e., stands to regions and days to centuries?

A major premise of this task is that natural and anthropogenic stressors (e.g., climate change, nitrogen deposition, chemicals, management, etc.) will significantly alter key biogeochemical processes (availability, uptake and allocation of carbon, nitrogen and water) during the next decades and centuries. In turn, these changes will dramatically alter habitat quality and, ultimately, the distribution and abundance of wildlife populations. Our objective is to use MBL-GEM to simulate biogeochemical responses to multiple, interacting stressors, and thereby provide a basis for including these effects in comprehensive wildlife assessments.

These assessments will include a suite of spatially-explicit models (MBL-GEM, FORCLIM and PATCH) designed to simulate habitat and wildlife dynamics in real settings, initially the Upper South Santiam Watershed (USSW) in western Oregon. The models will track habitat conditions over time frames that are ecologically relevant, and will provide the tools for assessing impacts on wildlife populations from projected natural and anthropogenic disturbances. See the Terrestrial Habitats Project QAPP and the USSW case study QATP for specifics.

A number of simulations are planned for the USSW case study, contingent upon initial results from model calibration and validation. This will include simulations that assess the effects of various stressor scenarios on ecosystem and landscape-scale biogeochemical cycles. Scenarios representing projected changes in climate, fire frequency and forest management will be constructed to examine long-term changes (decades to centuries) in ecosystem structure and function. These results will be used to drive the FORCLIM plant community model, which will generate habitat maps for the PATCH wildlife model. Specific studies are described fully in the QATP for the USSW case study.

1.2 • Products and Timetable

The primary product of this task will be a generally applicable biogeochemistry model (MBL-GEM) capable of simulating the effects multiple natural and anthropogenic stressors on carbon (C), nitrogen (N) and water dynamics across large spatial and temporal and scales, initially within the 50,000 hectare Upper South Santiam Watershed (USSW) in western Oregon. We will calibrate and validate MBL-GEM (version 6) for the USSW during FY2004, with initial manuscripts aimed at stand-level analysis of biogeochemical responses to stress. Watershed-scale analyses will follow in FY2005-2006. Spatially-explicit output produced from those simulations will be used to drive a plant community model to simulate decade- to century-scale changes in the quality and distribution of wildlife habitat in the USSW (see FORCLIM model QATP for details). The resulting habitat maps will be used to drive a spatially-specific wildlife model (PATCH) to predict stressor effects on wildlife populations within the study area (see PATCH model QATP for details).

The APMs associated with this Task are listed in the Project's QAPP, in Table 3. A timeline for this Task is illustrated in the Project's QAPP, in Figure 1.

1.3 • Project Personnel

Dr. Robert McKane will be responsible for calibrating and validating the MBL-GEM model. This will include preparing modeling data, conducting simulations, and analyzing and writing up results. EPA scientific staff contributing to the collection and analysis of supporting data include: Dr. Peter Beedlow, Dr. William Hogsett, Dr. Mark Johnson, Dr. E. Henry Lee, Dr. Donald Phillips, Dr. Allen Solomon, Dr. David Tingey, Ronald Waschmann and Constance Burdick.

1.4 • Support Facilities and Services

Table 1 lists the facilities and services needed to carry out specific tasks that support development of MBL-GEM. EPA-WED laboratory facilities have already been made available and are being used to analyze field samples in support of model calibration and validation. Work on GIS database development has begun under several contracts but will need to continue through year 3 or 4. Visualization resources will be needed for the duration of the project.

2. Model Description

2.1 • Model Overview

Table 1. Support Facilities

Facility	Type	Tasks
ISIRF	Federal On-site	Processing & analyzing isotope samples
Tree Ring Laboratory		Analysis of habitat productivity
PEB 114, 115		Processing & analysis of field samples
PEB 118		Staging and storage of field equipment
PEB 119, 108		Sample storage & archiving
EPA Scientific Visualization Center	Federal Off-site	Presentation of model output
Dynamac, Inc.	Non-Federal On-site	Soil GIS database development
Computer Science Corp.		Vegetation GIS database development
Senior Environmental Employment Program		Sample processing / data analysis for model calibration & validation
Oregon Climate Service	Non-Federal Off-site	Climate GIS database development

Available Biogeochemistry Models

There are a number of models available that simulate biogeochemical cycling in terrestrial ecosystems (Perruchoud and Fischlin 1995), including CASA (Potter et al. 1993), CENTURY (Parton et al. 1987), FOREST-BGC (Running 1994), LINKAGES (Pastor and Post 1986), MBL-GEM (Rastetter et al. 1991), PNET (Aber and Federer 1992) and TEM (Raich et al. 1991). Although all of these models provide a process-based view of ecosystem C and N cycling, they differ with respect to model structure (number of plant and soil compartments), mechanistic vs. empirical representation of processes, coupling with the abiotic environment, time step, and method of model calibration. Our objectives require a mechanistically-based model that can address short to long-term (days to centuries) responses of ecosystems to disturbances such as changes in climate,CO2, N deposition, and management. Further, these responses must encompass enzymatic controls on C and N acquisition, stoichiometric shifts in the chemistry of tissues, changes in plant biomass allocation among tissues, altered rates of organic matter turnover and N mineralization, and ultimately the redistribution of C and N between soils and vegetation. Because it would be extremely difficult to obtain sufficient fine-scale data to characterize many of these processes, we also require a model that can be calibrated to infer the needed information from data that are more easily obtained, namely, data collected at the scales of ecosystems (e.g., net primary production) and regions (e.g., vegetation C stocks along temperature and precipitation gradients).

Model Selection

We selected the Marine Biological Laboratory's General Ecosystem Model, or MBL-GEM (Rastetter et al. 1991, Rastetter and Kwiatkowski 2002), for application to the Terrestrial Habitats Project because it most closely meets the preceding requirements, i.e., it provides a mechanistic view of the processes of C, N and water acquisition and redistribution in plants and soils, simulates responses to multiple, interacting stressors, and can be calibrated using ecosystem- and regional-scale data. The model is generally applicable to most terrestrial ecosystems and, in its original form, has been used to analyze the responses of temperate deciduous forests, tropical evergreen forests, and arctic tundra to changes in CO2 concentration, temperature, N inputs, irradiance, and soil moisture (Rastetter et al. 1991, 1992, 1997; McKane et al. 1995, 1997a, 1997b, Hobbie et al. 1998, Clein et al. 2000). In addition, a regionally robust parameterization of MBL-GEM has already been established for PNW forests (McKane et al. 1997c). Biogeochemistry models previously applied to this region have had to be re-parameterized for different habitats, or run with values of key vegetation properties (e.g., leaf area) pre-specified as model drivers (Running et al. 1994). Those approaches limit a model's usefulness for habitat assessments across large spatial and temporal scales.

The new version of MBL-GEM, version 6 (Rastetter and Kwiatkowski 2002a, 2002b), simulates transient (nonequilibrium) ecosystem dynamics at temporal scales of days to centuries. The ability of MBL-GEM to simulate stressor effects on a daily time step is particularly important for our objectives. For example, projected decreases in winter snowpack and the timing and intensity of summer drought within the Pacific Northwest are expected to dramatically alter habitat quality and distribution within the next 50 years (National Assessment Synthesis Team 2001). The processes represented in MBL-GEM will allow us to predict and analyze how multiple stressors affect key biogeochemical transformations that directly or indirectly control changes in habitat quality. See the South Santiam Case Study QAPP and Terrestrial Habitats Research Plan (Schumaker et al. 2003) for a detailed description of modeling objectives and activities.

2.2 • Model Parameters

A detailed description of the MBL-GEM model structure, parameters and equations is provided in Rastetter and Kwiatkowski (2002a), MBL-GEM Model Structure and Equations, Version 6.

2.3 • Computer Aspects

MBL-GEM is written in Delphi 6.0, a Pascal-based programming language developed by Borland. Delphi is object oriented with a native code compiler that runs under Microsoft Windows or Linux-based systems. MBL-GEM is written for Windows systems and can be run using a standard laptop or desktop pc. However, a minimum of 512MB of memory is recommended to reduce simulation time. With this amount of memory the model will simulate 100 years of forest regrowth in approximately 5 minutes.

2.4 • Data Sources and Quality

Data to be used for calibrating, validating and applying MBL-GEM is described in detail the QATP for the Terrestrial Habitats Project's Upper South Santiam Case Study. That QATP and the

SOPs included therein will establish sampling protocols and procedures for determining the precision, accuracy, representativeness and completeness of the data for this modeling task.

2.5 • Data Management

Datasets will be processed and stored on a Windows pc in the office of the principal investigator. Backup procedures are those of the standard WED computer backup system.

3. MODEL DEVELOPMENT

3.1 • Code Development and Maintenance

Dr. Edward Rastetter and Bonnie Kwiatkowski of the Marine Biological Laboratory in Woods Hole, MA wrote the program code for MBL-GEM. They maintain the code and supporting documentation (model structure, parameter definitions, equations and calibration information) on the following website: *http://ecosystems.mbl.edu/Research/Models/gem/welcome.html*.

3.2 • Model Documentation

Complete documentation for MBL-GEM is provided in two documents: MBL-GEM Model Structure and Equations, Version 6 and MBL-GEM User's Manual, Version 6 by Dr. Edward Rastetter and Bonnie Kwiatkowski (2002a, 2002b). The full citations for these documents are listed at the end of this QATP and are available from the authors or Dr. Robert McKane.

MBL-GEM Model Structure and Equations, Version 6 includes:

- A complete description of the model structure.
- The equations on which the model is based.
- A complete list of variable names and definitions.

MBL-GEM User's Manual, Version 6 includes instructions for:

- Operating the Windows-based graphical user interface.
- Preparing data input files.
- Calibrating the model.
- Viewing and testing model output.

The MBL-GEM website (see section 3.1, above) also provides complete input and output files to be used as examples.

3.3 • Code Verification

Verification of the model code prior to version 6 is presented in 11 peer-reviewed publications in *Ecology*, *Ecological Applications*, *Global Biogeochemical Cycles*, *Tree Physiology*, *Global Change Biology*, *Forest Ecology and Management* and other journals. Those papers describe the application of MBL-GEM to various ecosystems, e.g., arctic tundra, tropical and temperate forests, and grasslands. The publications are listed in the references for this QATP and the MBL-GEM website (see section 3.1, above).

Modifications to the code for MBL-GEM version 6 will be verified under this QATP using the same procedures outlined in the earlier publications (McKane et al. 1997a and 1997b; Homann et al. 2000). These procedures involve comparison of model output to experimental data used for both calibration and validation, and contribute to characterizing the error (uncertainty) associated with the processes and state variables represented in the model (see section 4.3, below, for details).

3.4 • Code Documentation

The computer code for MBL-GEM version 6 is publicly available through the MBL-GEM website (see section 3.1). This code has been inspected and tested by the authors with respect to structure, logical errors and internal documentation. As the primary "beta tester" of MBL-GEM, Dr. Robert McKane will further inspect and verify the code. This process mainly involves exercising the model against real and theoretical changes in model drivers, state variables and parameters. The objective is to test the model against a wider a range of conditions than would be expected in the real ecosystems to which the model will be applied. If problems are identified, this information is passed back to the authors, who then correct and document the solutions to any problems. All corrections to the model code are followed by a final round of beta testing. A permanent QA record will be maintained for all beta testing procedures and results, including files documenting changes in model parameters and drivers.

4. MODEL APPLICATION

4.1 • Model Calibration

The objective of our calibration procedure will be to derive a single parameter set of MBL-GEM for Pacific Northwest forests. This single parameterization will need to accurately simulate the extreme differences in ecosystem carbon, nitrogen and water dynamics that occur in response to steep regional gradients in climate, soils and vegetation. Derivation of a single parameter set will ensure that simulated ecosystem dynamics across locations are due entirely to differences in the environmental drivers, not to differences in parameters used to simulate different treatments. This will facilitate our analysis of the experimental data in a way that is consistent across all sites, including the assignment of confidence ranges to projected changes in ecosystem components and processes (Gardner and Trabalka 1985).

We will calibrate MBL-GEM using data for a 200-km transect of 10 sites across Oregon, from coastal rainforest to semi-arid savanna east of the Cascade Range. The specific sites and data to be used for model calibration are described in the QATP for the USSW Case Study. Details of the calibration procedure for MBL-GEM are described in Rastetter and Kwiatkowski 2002b. This procedure will initially be applied to a site located midway along the Oregon transect. Once the model simulates the experimental data for that site, the procedure will then be applied to the next closest site. This will require an iterative adjustment of model parameters until data for both sites are accurately simulated. The procedure will then repeated for each additional site until the parameterization accurately simulates all ten sites. Previous regional assessments for the Amazon Basin (McKane et al. 1995) and Arctic tundra (McKane et al. 1997a, 1997b) have demonstrated that this procedure is the most effective means for calibrating the parameters that regulate ecosystem response to multiple, interacting stressors.

4.2 • Model Validation

We will validate the MBL-GEM parameterization for the Oregon transect against data collected for a transect of four sites in the Olympic National Park, WA. Because their climatic, edaphic and biological conditions cover a greater range than in Oregon, the Olympic sites will provide a severe test of the calibrated model. The same methods and data have been used to collect experimental data at the Oregon and Olympic sites, thereby eliminating the problem of data comparability that frequently undermines attempts to validate ecological models. We will use the statistical procedures outlined in section 4.3, below, to assess the success of our model validation effort.

4.3 • Model Uncertainty

Discrepancies between model output and observations may be caused by calibration procedures, specific equations and/or parameters, and data quality (Homann et al 2000). We will use the following equation to quantify the uncertainty in model output associated with each of these discrepancies:

$$E_j = \frac{\sum_{i=1}^{n} \frac{|S_{iA} - O_i|}{|S_{iC} - O_i|}}{n} \qquad \text{(Equation 1)}$$

where E_j is the normalized absolute error for parameter j averaged over n output variables, S_{iA} is the simulated value of output variable i when the calibrated value of parameter j is increased or decreased by some amount, S_{iC} is the simulated value of output variable i for the calibrated value of parameter j, and O_i is the observed (experimentally measured) value of output variable i. Thus, $E_j = 1$ if a change in parameter j results in no change in the average absolute error, $E_j > 1$ if the error increases, and $E_j < 1$ if the error decreases. When all values of $E_j < 1$, the calibrated parameter set represents a best fit of the measured data (see McKane et al. 1997a for details). In practice, parameter j includes any parameter or state variable in the model that has uncertainty associated with it. This uncertainty may be well-quantified by experimental data or, in the case of parameters that are not physically based, may be unknown except through a sensitivity analysis of model behavior to arbitrary adjustments in the parameter (see *Uncertainty in Model Parameters*, below).

Uncertainty in Model Calibration

Our initial calibration of MBL-GEM to the Oregon Transect (section 4.1, above) will rely on a Monte-Carlo parameterization routine in MBL-GEM that minimizes the mean (all parameters) normalized absolute error for Equation 1 (above). Thus, our application of the model is analogous to a nonlinear regression analysis in which the model parameters are optimized to match all experimental observations, both within and across all 10 sites. The major advantage of our modeling approach over a conventional regression analysis is that the underlying equations in MBL-GEM are derived from the accumulated understanding of the processes involved.

Uncertainty in Model Parameters

Equation 1 will also be used to quantify uncertainty in the two types of parameters used to calibrate MBL-GEM. For data-based parameters, the measured experimental error (e.g., the standard error of the mean value of soil carbon for a given site) will be applied to Equation 1 determine the effect on model output. The second type of parameter is not directly defined by experimental data, but is instead used to “tune” or adjust the shape of response surfaces in the model. For example, the parameters that control the response of decomposition to air temperature and soil moisture need to be adjusted to match measured rates of detritus accumulation. A sensitivity analysis that systematically varies the values of these parameters around the calibrated value (e.g., a +10%) will be used to better understand model behavior (e.g., identification of sensitive rate constants, processes and system-level feedbacks), and to identify problems in the model code (e.g., equations having unstable equilibria).

Uncertainty in Model Validation

Finally, we will use a modified form of Equation 1 to assess our validation test of MBL-GEM for the Olympic National Park (section 4.2, above):

$$E_j = \frac{\sum_{i=1}^{n} |S_{iC} - O_i|}{n} \qquad \text{(Equation 2)}$$

where E_j, n, S_{iC}, and O_i are defined as for Equation 1. In this case, the model drivers (temperature, precipitation, etc.) for the Olympic sites will be applied to the calibrated parameters for the Oregon Transect. Equation 2 is then applied to the measured and simulated Olympic data. Comparison of the mean (all parameter) normalized absolute error for the calibration and validation steps will quantify the uncertainty associated with applying the model outside of its calibration range, i.e., its regional applicability.

5. ASSESSMENT / OVERSIGHT

5.1 • Monitoring

Dr. Robert McKane will provide oversight for the MBL-GEM modeling task. He will periodically review the status of all datasets and model software for integrity and completeness. These reviews will occur both when problems are suspected and in random inspections.

5.2 • Reporting

The primary form of reporting for this project will be manuscripts and reports describing results of investigations. This reporting will include considerations of data quality and model uncertainty discussed in the preceding sections.

6. REFERENCES

Aber JD, Federer CA (1992). A generalized, lumped-parameter model for photosynthesis, evapotranspiration and net primary production in temperate and boreal forest ecosystems. Oecologia 92:463-474.

Clein, J. S., B. L. Kwiatkowski, A. D. McGuire, J. E. Hobbie, E. B. Rastetter, J. M. Melillo and D. W. Kicklighter. 2000. Modelling carbon responses of tundra ecosystems to historical and projected climate: A comparison of a plot- and a global-scale ecosystem model to identify process-based uncertainties. Global Change Biology Vol. 6, Supplement I:127-140.

Hobbie, J. E., B. L. Kwiatkowski, E. B. Rastetter, D. A. Walker and R. B. McKane. 1998. Carbon cycling in the Kuparuk Basin: Plant production, carbon storage, and sensitivity to future changes. Journal of Geophysical Research 103:29,065-29,073.

Homann, P.S., R.B. McKane, and P. Sollins. 2000. Belowground processes in forest ecosystem biogeochemical simulation models. Forest Ecology and Management 138:3-18. Also published in J.R. Boyle and R.F. Powers (ed.). 2001. Forest Soils and Ecosystem Sustainability. Elsevier, New York.

McKane, R. B., E. B. Rastetter, J. M. Melillo, G. R. Shaver, C. S. Hopkinson, D. N. Fernandes, D. L. Skole and W. H. Chomentowski. 1995. Effects of global change on carbon storage in tropical forests of South America. Global Biogeochemical Cycles 9(3):329-350.

McKane, R., E. Rastetter, G. Shaver, K. Nadelhoffer, A. Giblin, J. Laundre and F. Chapin. 1997a. Climatic effects on tundra carbon storage inferred from experimental data and a model. Ecology 78:1170-1187.

McKane, R., E. Rastetter, G. Shaver, K. Nadelhoffer, A. Giblin, J. Laundre and F. Chapin. 1997b. Reconstruction and analysis of historical changes in carbon storage in arctic tundra. Ecology 78:1188-1198.

McKane R, Tingey D, Beedlow P, Rygiewicz P, Johnson M, Lewis J. (1997c). Spatial and temporal scaling of CO2 and temperature effects on Pacific Northwest forest ecosystems. American Association for the Advancement of Science Pacific Division Abstracts 16(1):56.

National Assessment Synthesis Team (2001). Climate Change Impacts on the United States: The Potential Consequences of Climate Variability and Change. Report for the US Global Changes Research Program, Cambridge University Press, Cambridge UK, 620pp.

Parton WJ, Schimel DS, Cole CV, Ojima DS (1987). Analysis of factors controlling soil organic matter levels in Great Plains grasslands. Soil Science Society of America Journal 51:1173-1179.

Pastor J, Post WM (1986). Influence of climate, soil moisture, and succession on forest carbon and nitrogen cycles. Biogeochemistry 2:3-27.

Potter CS, Randerson JT, Field CB, Matson PA, Vitousek PM, Mooney HA, Klooster SA (1993). Terrestrial ecosystem production: a process model based on global satellite and surface data. Biogeochemical Cycles 7:811-841.

Raich JW, Rastetter EB, Melillo JM, Kicklighter DW, Steudler PA, Peterson BJ, Grace AL, Moore B III, Vorosmarty CJ (1991). Potential net primary productivity in South America: Application of a global model. Ecological Applications 1:399-429.

Rastetter, E. B., M. G. Ryan, G. R. Shaver, J. M. Melillo, K. J. Nadelhoffer, J. E. Hobbie and J. D. Aber. 1991. A general biogeochemical model describing the responses of the C and N cycles in terrestrial ecosystems to changes in CO2, climate and N deposition. Tree Physiology 9:101-126.

Rastetter, E. B., R. B. McKane, G. R. Shaver and J. M. Melillo. 1992. Changes in C storage by terrestrial ecosystems: How C-N interactions restrict responses to CO2 and temperature. Water, Air & Soil Pollution 64:327-344.

Rastetter, E. B., R. B. McKane, G. R. Shaver, K. J. Nadelhoffer and A. E. Giblin. 1997. Analysis of CO2, temperature, and moisture effects on carbon storage in Alaskan arctic tundra using a general ecosystem model, pp.437-451. In: W. C. Oechel, T. Callaghan, T. Gilmanov, J. I. Holten, B. Maxwell, U. Molau and B. Sveinbjörnsson (eds.), Global Change and Arctic Terrestrial Ecosystems. Springer-Verlag, New York.

Rastetter, E. B.and B. L. Kwiatkowski. 2002a. MBL-GEM Model Structure and Equations, Version 6. The Ecosystems Center, Marine Biological Laboratory, Woods Hole, MA 02543.

Rastetter, E. B.and B. L. Kwiatkowski. 2002b. MBL-GEM User's Manual, Version 6. The Ecosystems Center, Marine Biological Laboratory, Woods Hole, MA 02543.

Running, SW (1994). Testing FOREST-BGC ecosystem process simulations across a climatic gradient in Oregon. Ecological Applications 4:238-247.

Appendix 3

Quality Assurance Task Plan
for the
FORCLIM Model Development Project

Version 1.3 *August 17, 2005*

1. TASK DESCRIPTION

1.1 • Overview and Objectives

The Task's principle objective is to develop the capability to project the future annual spatial distribution and condition of wildlife habitats at landscape scales, incorporating effects of major ecosystem disturbance frequencies and intensities.

This appendix to the Habitat Project QAPP addresses simulation modeling of forest dynamics. Part of the approach to understanding the mechanisms governing the survival of wildlife species is creating models (PATCH) that simulate annual population dynamics on realistic landscapes, on the one hand, and the changing habitats in which wildlife species complete their life cycles (forest gap model FORCLIM), on the other. See the Project QAPP and study plan (Schumaker et al. 2003) for more description of overall Project activities.

The goal of the stand modeling work is to modify an available forest gap model program (FORCLIM) to simulate dynamic vegetation structure and composition for wildlife habitat and biogeochemical cycling model applications. This goal requires changes in capability of an available gap model, as well as linking or integrating a gap model with both the PATCH wildlife population model and the GEM biogeochemical cycling model. Both of these advances depend on the gap model chosen. Our conclusion, based on the data available from a recent test of gap model capabilities (Busing and Solomon, 2003), and on past experience in gap model development, is that beginning with FORCLIM and its accurate replication of stand structural characteristics will be most straightforward, with a high likelihood of eventual success. In addition, the other model of choice, ZELIG, proved in the same recent test to be inappropriate for the tasks of a dynamic habitat model. Hence, the remaining QAPP deals only with that model.

1.2 • Products and Timetable

The key tasks and products expected from this research are tabled in the QAPP for the USGS-EPA IAG, and are not repeated here. The fundamental product is a completed dynamic wildlife habitat model linked to PATCH. Other features of the model called for in the QA Assurance Guidelines for Modeling are provided in the section below labelled *Model Description*.

The APMs associated with this Task are listed in the Project's QAPP, in Table 3. A timeline for this Task is illustrated in the Project's QAPP, in Figure 1.

1.3 • Project Personnel

Dr. Allen Solomon will oversee the FORCLIM development task. However, this task requires more expertise than is available at WED. Additional requisite expertise does exist within USGS and is being accessed via the IAG which underlies this research. WED currently is covering the costs of a full-time USGS programmer (Dr. Richard Busing) who is devoted 100% to this project. Dr. Allen Solomon, WED, oversees Busing's work. Dr. Sarah Shafer, a vegetation modeler with USGS Geology Division, is working with the USGS ecological programmers and with WED scientific staff to help define and develop the necessary model modifications. Note that this IAG includes additional work related to but independent of the habitat modeling objectives, to develop a predictive model of climate and vegetation control of wildfire in the western U.S. This work is described in detail by Hostetler et al. (2001). Dr. Stephen Hostetler works closely with Drs. Shafer and Solomon, and is the direct supervisor of Dr. Busing. USGS and Dr. Hostetler are responsible for the QA of the wildfire modeling research.

1.4 • Support Facilities and Services

The facilities needed for model development center around computers. When the gap model FORCLIM is migrated from its Mac platform written in Modula 2, to a PC platform written in

Microsoft C#.NET (fall or winter, 2003), available computer facilities (PCs running at 900 Mhz and 2400 Mhz) will be quite adequate for the work.

2. Model Description

2.1 • Model Overview

Future wildlife populations will be affected by habitat modifications caused by many changing forces: shifting land uses that displace habitat, chronic climate changes that transform habitat, climate and land use changes combining to modify disturbance regimes that destroy habitat, fugitive herbicides and other management actions that degrade habitat, and so on. The need to predict wildlife population responses requires reliable estimates of the changes in habitats induced by these forces.

The PATCH model (Schumaker, 1998) developed at WED is expected to be applied to predicting future wildlife population dynamics. It mimics population demographic processes (birth, movement, reproduction, death) on spatially-explicit landscapes composed of habitat units of uniform size. An advantage in applying PATCH to a broad range of applications is its flexible spatial nature, which depends only on sizes of the habitat units defined by model programmers. Yet, this flexibility also is a liability in that changing habitat characteristics must be estimated without reference to the outcomes of processes which operate at different scales to define the habitat changes: plant population demography, plant community succession, ecosystem disturbance by various forces, and so on. Gap models such as FORCLIM (Bugmann, 1994) are a type of vegetation model that does, or can be programmed to, simulate these processes. Gap models at scales from that of stands covering less than a hectare to landscapes covering thousands of hectares have been developed and/or used at WED for several years (e.g., Solomon and Bartlein, 1992; Solomon and West, 1993; Bugmann and Solomon, 1995, 2000).

Scope

Before they can provide adequate dynamic habitat output for PATCH, the gap models must be modified to mimic certain plant demography, vegetation structure, succession and disturbance phenomena. We will modify FORCLIM v.2.9, described by Bugmann and Solomon (2000), to:

1. Increase the realism of the simulated three dimensional structure of forest vegetation during plant succession by applying allometric data from the forestry literature to modeled species growth.
2. Add routines to simulate the presence and persistence of non-forest vegetation.
3. Incorporate one of the several wildfire routines already written for gap models.
4. Create a routine to describe effects of forest pests as a function of vegetation age, structure, and composition.
5. Complete development of simulated landscape-level processes of propagule transport and species establishment, using the PATCH grid system as the modeled spatially-explicit landscape.

Nature of Forest Succession Models

Forest succession models (also referred to as gap or stand models) mimic the dynamics of tree establishment, growth and mortality by multiple species of differing ages in a gap in an otherwise continuous forest canopy, created by the death of a dominant tree. There, the models simulate interspecific competition for sunlight, water and nutrients based on individual species differences in shade tolerance, drought tolerance, and nutrient requirements. They simulate the vertical characteristics of tree density on a plot of specified area and they calculate the amount of light which reaches each vertical level as a function of the leaf areas above that level. They assume that the maximum dimensions of a tree species (maximum diameter, height and age) ever measured are also the maximum each species could reach under ideal light, climate, and nutrient conditions.

Those conditions are calculated annually, and rarely if ever occur either in nature or in the models. Instead the growth maxima are reduced under non-optimal shading, climate and nutrient supplies.

The greatest advantage of stand models for terrestrial wildlife habitat research goals is their ability to capture the year-to-year changes to be expected in forest structural characteristics: changing size and age distributions of individuals from each species as a function of yearly variations in temperature, soil moisture, and other environmental properties. Their greatest weakness for our purposes is in their inability to predict the dynamics on any given plot or set of plots, without very detailed information on plot history: major disturbances, species available to establish following each disturbance, weather conditions and soil moisture available throughout initial growing seasons of seedling establishment, and so on (Solomon, 1987). These historic constraints on future forest dynamics are normally treated in forest gap models as stochastic properties. Hence, gap models can be applied to predict future statistical properties of forest stands grouped at landscape and regional scales, but not of individual plots in any specified location.

Available Forest Succession Models

Gap models have been applied in Pacific Northwest forests for 20 years (Hemstrom and Dale, 1982; Dale and Hemstrom, 1984; Kercher and Axelrod, 1984; Urban et al., 1993; Burton and Cummings, 1995; Bugmann and Solomon, 2000). Each varies in capability and validity, none being well-suited to the problem of dynamic habitat simulation. Variables and parameters in the ZELIG model (Urban et al., 1993) have been calibrated to work very well at the H. J. Andrews Long Term Ecological Research Site in the central Cascades of Oregon (ZELIG2.PNW; Stephen Garman, Pers. Comm., 4/03; Busing and Solomon, 2003). Because we will be simulating conditions in locations other than H. J. Andrews, we expect to use the FORCLIM model which we have been developing to simulate forest succession in a variety of the world's temperate forests (Bugmann and Solomon, 2000).

FORCLIM Forest Succession Model

The FORCLIM model v.2.6 (Bugmann 1994) was developed and tested for accuracy under central European conditions, based on the model FORECE (Kienast 1987). It worked equally accurately with forests of eastern North America (Bugmann and Solomon, 1995) and was modified to simulate forests of the Pacific Northwest (FORCLIM v.2.9; Bugmann and Solomon, 2000). FORCLIM was designed to incorporate reliable yet simple formulations of climatic influences on ecological processes, using a minimum number of ecological assumptions. FORCLIM consists of three modular submodels, each of which can be run independently, or combined:

1. FORCLIM-E, a submodel for generating monthly and annual values describing the abiotic environment.
2. FORCLIM-S, a submodel of soil carbon and nitrogen turnover.
3. FORCLIM-P, a submodel of tree population dynamics based on the gap hypothesis of Watt (1947) and modeled by Botkin et al (1972) and Shugart (1984).

Tree growth rates in FORCLIM V2.9 are constrained by light availability, soil nitrogen level, summer warmth and seasonal water stress (Figure 1). Light availability through the canopy is calculated using the Beer-Lambert law (Monsi et al., 1973) applied to leaf areas simulated at each meter vertical level. The approach by Aber et al. (1979) and Pastor and Post (1987) is the basis for defining the influence of nitrogen availability on tree growth. The effect of summer temperature on tree growth is calculated using a half-parabolic relationship between the annual sum of growing degree-days (GDD) above a 5.5 °C threshold and the growth rate of the trees between the minimum (lowest GDD in a species' geographic range) and the optimum value (mid-GDD value in a species' geographic range). Drought stress is expressed as the growing season evapotranspiration deficit, i.e. 1 - AET/PET (Prentice et al. 1993), where AET and PET are the annual sums of actual and potential evapotranspiration, respectively ("drought index").

2.2 • Model parameters

The FORCLIM model incorporates natural history parameters for each of the tree species included in simulations. We have parameterized 45 species of Pacific Northwest trees, reproduced in Figure 1, below.

Autecological information is retrieved directly from silvics manuals (e.g., Burns and Honcala, 1991) and includes: DiaMax, the maximum known diameter in cm; HtMx, the maximum known height in meters; AgMx, the maximum known age in years; LtTol, the shade tolerance on a scale from 1 (very tolerant) to 9 (very intolerant); LtMn, the minimum light required by subcanopy trees to survive, as a percentage of light at the top of the canopy; LtMx, the maximum light subcanopy trees can survive, as a percentage of light at the top of the canopy; and LtSds, the minimum light required by seedling trees to survive, as a percentage of light at the top of the canopy.

Climatic limits are derived either from Thompson et al. (1999) or from superimposing transparent maps of climate variables from available data sets (e.g., Dotson et al., 1997) on paper maps of tree species geographic range (Little, 1971). These include DDMin, the degree day minimum in oC; WTmn, the winter temperature minimum in ^{o}C; WTmx, the winter temperature maximum in oC; and DrTol, the maximum drought tolerance as a percentage of the growing season in which soil water is below the wilting point.

Thus far, parameters for nutrient tolerance have not been assembled and the nutrient response routines have been turned off in past simulations, although natural history information is available to fill this void. Instead, we plan to utilize the developed capabilities of the GEM biogeochemical cycling model to generate nutrient constraints on simulated trees. Additional natural history parameters to characterize the new vegetation structure and disturbance routines described above will be created the same way as described for the current parameters.

Table 1. Tree Species Parameters used in FORCLIM

Genus	Dia Max	Ht Max	Ag Max	DD Min	WT Min	WT Max	Dr Tol	Lt Tol	Lt Min	Lt Max	Lt Sds
Abies amabilis	200	75	600	390	-10	0	0.4	1	0.01	1	.01-1
Abies grandis	225	76	300	705	-12	3	0.45	3	0.3	0.7	.3-.7
Abies lasiocarpa	80	40	300	300	-40	-7	0.35	3	0.01	1	.3-1
Abies magnifica	366	70	500	400	-8	2	0.3	3	0.3	1	.01-1
Abies procera	275	85	600	821	-7	3	0.3	7	0.3	1	.3-1
Acer macrophyllum	300	28	300	705	-3	7	0.45	3	0.01	0.7	.01-7
Alnus rubra	130	38	150	705	0	8	0.3	7	0.9	1	.9-1
Arbutus menziesii	150	34	500	965	0	8	0.45	3	0.3	1	.7-1
Castanopsis chrysophyl	244	46	500	800	-5	8	0.6	5	0.3	0.7	.3-.7
Chamaecyparis nootkat	370	53	3500	390	-14	-1	0.25	1	0.3	1	.1-.7
Chamaecyparis lawson	183	61	560	1200	-2	5	0.25	3	0.1	0.7	.3-1
Fraxinus latifolia	150	48	250	800	0	9	0.65	5	0.3	1	.3-1
Juniperus occidentalis	414	27	1000	500	-12	-2	0.55	9	0.9	1	.9-1
Juniperus scopulorum	46	15	3000	400	-9	4	0.5	7	0.3	1	.3-1
Larix lyallii	201	46	1000	300	-14	-7	0.1	9	0.9	1	.9-1
Larix occidentalis	230	61	900	800	-9	3	0.3	9	0.3	1	.3-1
Libocedrus decurrens	375	69	542	400	-7	8	0.4	5	0.3	0.7	.3-.7
Lithocarpus densiflorus	137	63	300	1200	-1	6	0.6	3	0.01	0.7	.01-.7
Picea englemanii	244	55	600	488	-40	-3	0.4	3	0.1	0.7	.1-.7
Picea sitchensis	500	90	800	1252	0	5	0.2	3	0.01	1	.01-1
Pinus albicaulis	267	26	1000	400	-16	-7	0.1	7	0.9	1	.9-1

Table 1. Tree Species Parameters used in FORCLIM

Genus	Dia Max	Ht Max	Ag Max	DD Min	WT Min	WT Max	Dr Tol	Lt Tol	Lt Min	Lt Max	Lt Sds
Pinus contorta contorta	50	10	500	1252	3	7	0.35	9	0.9	1	.9-1
Pinus contorta latifolia	213	46	600	524	-15	-9	0.35	9	0.9	1	.9-1
Pinus edulis	172	21	1000	800	-10	4	0.5	9	0.9	1	.9-1
Pinus flexilis	274	26	300	400	-16	-8	0.2	7	0.9	1.9-1	
Pinus jeffreyi	229	61	600	450	-13	2	0.4	7	0.7	1	.7-1
Pinus lambertiana	310	76	623	2000	-5	8	0.25	7	0.3	1	.3-1
Pinus monophylla	100	14	600	2000	-6	4	0.4	9	0.9	1	.9-1
Pinus monticola	200	75	600	589	-12	3	0.3	5	0.3	1	.3-1
Pinus ponderosa	275	80	600	965	-12	8	0.55	7	0.3	1	.3-1
Pinus sabiniana	160	49	200	2000	1	8	0.45	9	0.3	1	.3-1
Populus tremuloides	75	22	200	100	-25	-3	0.4	9	0.95	1	.95-1
Populus trichocharpa	300	68	172	100	-13	5	0.7	9	0.95	1	.95-1
Pseudotsuga menziesii g.	250	54	700	633	-15	-5	0.4	5	0.3	1	.3-1
Pseudotsuga menziesii m.	425	117	1400	633	-10	5	0.4	7	0.9	1	.9-1
Quercus chrysolepis	152	30	300	500	3	7	0.4	7	0.01	0.7	.01-.7
Quercus garryana	250	37	500	677	-4	6	0.5	5	0.3	0.7	.3-.7
Quercus kelloggii	274	38	500	1600	-1	8	0.5	7	0.3	0.7	.3-.7
Sequoia sempervirens	600	120	2200	2000	0	7	0.3	1	0.3	1	.3-1
Taxus brevifolia	142	23	375	1200	-11	4	0.4	1	0.01	0.1	.01-.1
Thuja plicata	350	76	1500	748	-8	3	0.25	1	0.01	0.3	.01-.3
Tsuga heterophylla	275	80	700	719	-8	4	0.25	1	0.01	0.3	.01-.3

Table 1. Tree Species Parameters used in FORCLIM

Genus	Dia Max	Ht Max	Ag Max	DD Min	WT Min	WT Max	Dr Tol	Lt Tol	Lt Min	Lt Max	Lt Sds
Tsuga mertensiana	150	46	800	300	-15	-3	0.35	3	0.01	0.7	.01-.3
Umbellularia californica	404	53	300	800	-1	10	0.4	3	0.01	0.7	.01-.7

2.3 • Computer Aspects

The current programming language of FORCLIM 2.9 is Modula 2, as written for Apple MacIntosh computers, and running under a MacIntosh shell, "RAMSES" by Fischlin et al. (http://www.ito.umnw.ethz.ch/SysEcol/SimSoftware/RAMSES/RAMSES_Welcome.html).

In addition, a version of the model written in C and running under UNIX system is also available and being used for model testing purposes (e.g., Busing and Solomon, 2003). At this writing (November, 2003) the model FORCLIM is being translated into Microsoft C#.NET by H. K. M. Bugmann under a contract with WED, for use under the Windows operating system. That version should be available in fall or winter, 2003. The C#.NET version of FORCLIM should be very portable and operate on any machine that runs Windows 2000 or higher. Memory requirements are minimal (64 Mb of RAM on a Mac, 256 Mb RAM on a PC).

Hardware requirements for the currently-available version include a MacIntosh running OS 8 or higher, with a monitor, keyboard and connection to a printer, or any UNIX machine running the current Sun OS. Execution time for a typical run of 600 simulated years is a minute or two under Mac OS, and a second or less under UNIX.

2.4 • Data Sources and Quality

The kinds of data required to run the model include the natural history data that underlie species parameters, plus actual land cover and vegetation variables used in model verification exercises, and monthly weather variables (average temperature, precipitation). The vegetation and weather data are taken directly from large, commercial or governmental databases as appropriate to the specific simulations, and hence already undergo adequate QA/QC procedures. Metadata (published sources, the nature of and logic for modifications, data formats) for all such data sets are archived on computer hard drives and in back up files.

The quality assurance of natural history data are more ambiguous. As mentioned above, the parameters relating to species environmental tolerances are simply taken directly from values provided by Burns and Honcala (1991), Thompson et al (1999), and other compendia. However, a fundamental problem involves the difficulty of defining environmental tolerances of species from their co-occurring spatial distributions in montane regions of very steep environmental gradients. Normally, one superimposes a map of an environmental variable on a map of a species geographic range, and records the environmental limits found within that species range. The method originated with the stand model concept (Botkin et al., 1972). It remains the primary means for defining species limits, although Bugmann and Solomon (2000) refined it to utilize the most extreme values, not just the broad range values at one range edge or another, in order to include the maximum niche space each species can be proven to occupy. However, recording the coldest winter temperature or the driest soil moisture tolerated by a species which grows over a range of 1000 m elevation may encompass a horizontal distance of only a few kilometers in very rough terrain. Few mapped distributions of species or environmental variables are measured precisely enough for that application.

Others attempting to develop gap models in the Pacific Northwest (Dale and Hemstrom, 1984; Urban et al., 1993; Burton and Cummings, 1995) were unable to solve the problem in a way that generates objective, repeatable and accurate values. The recent work by Bugmann and Solomon (2000) indicated that even our “improved” approach is less accurate than needed for the purposes of regional vegetation estimation. Our spatial approach which overlays species' ranges onto 4_km climatic data, still provides only coarse estimates of the species' climatic limits, even where our climate data are accurate (and, the weather stations are too sparse for the data to be reliably so). Use of the 25 km square grids provided by Thompson et al. (1999) is even less realistic. A research approach to solving this problem with a combination of field data and terrain modeling was part of the WED Forest Indicators Project which was cancelled before the work could be initiated. Hence, this inability to insure reliable natural history data quality must remain as a weakness of the research project.

2.5 • Data Management

Allen M. Solomon will be responsible for modification and testing against forest survey data of the gap model FORCLIM, its linkage to the PATCH wildlife population model, and with Robert McKane, linkage to the GEM biogeochemical model. The FORCLIM work will be overseen primarily by a USGS programmer (Richard Busing) through an EPA-USGS IAG (DW-14958501). A QAPP was approved for that work including the model FORCLIM, July 18, 2003 (Modeling Environmental Disturbance Processes at Multiple Scales in the Western United States).

3. Model Development

3.1 • Code Development and Maintenance

QA for code development and maintenance will include a complete record of the model development, including specific modifications made in the code, and of the code validation process. The media trail for QA will consist of annual reports as well as past and current annotated computer files of source and object code and code changes and verification runs (input and output). The annual reports will include a description of model modifications with respect to objectives, assumptions, parameter values and sources, inputs used, output of model runs, interpretation, and any modification validation exercises.

3.2 • Model Documentation

QA procedures for documenting code will include complete descriptions of the equations on which the model is based, the underlying assumptions, the boundary conditions, and limiting conditions. An initial user's guide will be included by Bugmann and others with the FORCLIM.NET software to be delivered in fall or winter, 2003. As each modification of that code is completed and validated, changes to the user's guide will be written, including instructions for preparing data files, example problems comprising annotated input and output, programmer's instructions, and initial code verification.

3.3 • Code Verification

Included in the annual report on Code Development and Maintenance (C.1. above) will be descriptions of exercises carried out to assess the correctness and accuracy of the computational algorithms used to solve the governing equations and to assure the computer code is fully operational.

3.4 • Code Documentation

Computer code inspections will be carried out with each model modification and before model use, giving attention to internal documentation, code structure and compliance with programming standards. The documentation will include any changes in model specifications, model description, flow charts, data bases, and will include description of the new routines, and a source listing.

4. MODEL APPLICATION

4.1 • Model Calibration

FORCLIM 2.9 has been tested for its ability to reproduce stand biomass and species composition on a transect of 27 sites from the Oregon Coast near Reedsport, eastward across the Coast Range, the Willamette Valley, the Cascades, and into the cold desert near Bend, Oregon (Bugmann and Solomon, 2000). The model also has been tested against tree size distributions and species composition at three elevations (500 m, 1000 m, 1400 m) in the H. J. Andrews Long-Term

Ecological Research Site near Blue River, Oregon in the Santiam River headwaters (*ibid*.), and against 20 forest survey plots measured in each of the nine Ecoregions of western Oregon (Busing and Solomon, 2003). These tests reveal that the model functions adequately for many purposes in these areas.

4.2 • Model Validation

After each modification, the model will be operated for comparison of its' output to output derived from initial model runs, to determine whether changes in model behavior are those envisioned. The model will also be operated for comparison to actual vegetation data, to determine how well the model matches reality. Much of the actual vegetation data is being derived from Forest Inventory Analysis (FIA) data for private lands (Woudenberg and Farrenkopf, 1998; Azuma et al, 2002) and Continuous Vegetation Survey (CVS) for public lands in western Oregon and adjacent Washington (Max et al., 1996), reduced and formatted as described by Busing and Solomon (2003). As model development approaches the spatial development of habitat features that form the ultimate goal of the research, remotely-sensed data bases describing land cover and land use will be accessed as well (e.g., Hodges, 2002).

4.3 • Model Uncertainty

Much of the information required for model application QA has already been discussed, especially in sections 3 (Model Description) and 4 (Model Development). The suitability and restrictions on use are defined in section 3, and restrictions derived from assumptions, parameter values and sources, and validation of the model are found primarily in section 4 and 5. QA on interpretation of results will be affected primarily through the WED and journal peer reviews that precede publication of results.

Tree establishment rates in FORCLIM are determined stochastically, after eliminating species for which light availability at the forest floor, browsing intensity, winter chilling temperatures, and winter minimum temperature are inappropriate. The latter temperatures are assumed to be correlated with (but not the same as) the minimum of the current mean temperatures of December, January, and February (cf. Prentice et al. 1992).

Tree mortality is modeled as a combination of an age-related and a stress-induced mortality rate (Shugart 1984, Kienast 1987, Solomon & Bartlein 1992). As trees age, their probability of death increases. Also, minimal annual tree growth at any age increases the probability of death. The resulting mortality curve is a hyperbola, with maximum mortality in youngest and oldest tree classes. There is no direct influence of weather on mortality rates; however, trees that grow slowly due to adverse environmental conditions are more likely to die, which thus provides a linkage from weather to tree growth and to mortality.

However, as described under 2.1 above, neither FORCLIM nor any other forest gap model is currently suitable for direct application to habitat characterization in the PATCH wildlife model. The model must be modified to simulate non-forest vegetation, three-dimensional "physiognomy" of vegetation composition and structure, and effects of disturbances by wildfire, pests and so on, then linked via a spatial interface to the PATCH wildlife model.

5. ASSESSMENT AND OVERSIGHT

5.1 • Monitoring

Dr. Allen Solomon will provide oversight for the FORCLIM modeling task. He will periodically review the status of all datasets and model software for integrity and completeness. These reviews will occur both when problems are suspected and in random inspections.

5.2 • Reporting

The primary form of reporting for this project will be manuscripts and reports describing results of investigations. This reporting will include considerations of data quality and model uncertainty discussed in the proceeding sections.

6. REFERENCES

Aber, J. D., Botkin, D. B. & Melillo, J. M. 1979. Predicting the effects of different harvesting regimes on productivity and yield in northern hardwoods. Can. J. For. Res. 9:10-14.

Azuma, D. L., L. F. Bednar, B. A. Hiserote, and C. F. Veneklase. 2002. Timber resource statistics for western Oregon, 1997. USDA, For. Serv. PNW Res. Sta. Resource Bul. PNW-RB- 237. Portland, OR.

Botkin, D. B., Janak, J. F. & Wallis, J. R. 1972. Some ecological consequences of a computer model of forest growth. J. Ecol. 60:849-872.

Bugmann, H. K. M. 1996. A simplified forest model to study species composition along climate gradients. Ecology 77:2055-2074.

Bugmann, H. K. M. and A. M. Solomon. 1995. The use of a European forest model in North America: A study of ecosystem response to climate gradients. J. Biogeography 22:477-484.

Bugmann, H. K. M. and A. M. Solomon. 2000. Explaining forest composition and biomass across multiple biogeographical regions. Ecol. Applic. 10:95-114.

Burns, R. M. and B. H. Honkala. 1990. Silvics of North America. Volume 1, Conifers; Volume 2, Hardwoods. Agriculture Handbook 654, USDA Forest Service, Washington D.C.

Burton, P. J. & Cumming, S. G. 1995. Potential effects of climatic change on some western Canadian forests, based on phenological enhancements to a patch model of forest succession. Water, Air and Soil Poll. 82:401-414.

Busing, R. and A. M. Solomon. 2003. A comparison of forest survey data with forest dynamics simulators FORCLIM and ZELIG along climatic gradients in the Pacific Northwest, WED/ NHEERL/ORD, U.S.E.P.A. Draft Report, in review. 26p.

Dale, V. H. & Hemstrøm, M. 1984. CLIMACS: A computer model of forest stand development for western Oregon and Washington. Res. Paper PNW_327, Pacific Forest and Range Experiment Station, U.S. Department of Agriculture, Forest Service, Portland OR.

Hemstrom, M. and Dale, V. D. 1982. Modeling long-term forest succession in the Pacific Northwest. In: Means, J. E. (ed.), Forest Succession and Stand Development Research in the Northwest. Forest Research Laboratory, Oregon State University, Corvallis OR. pp. 14-23.

Hodges, J. 2002. MODIS MOD12 Land Cover and Land Cover Dynamics Products User Guide. Center for Remote Sensing, Department of Geography, Boston University, Boston, MA. http:// geography.bu.edu/landcover/userguidelc/.

Hostetler, S. W., P. J. Bartlein and A. M. Solomon. 2001. Climatic Controls of Fire in the Western United States: From the Atmosphere to Ecosystems. Proposal funded by U.S. Joint Fire Science Program (to R. Clark, U.S. B.L.M., Program Manager), 24p.

Kercher, J. R. and M. C. Axelrod. 1984. A process model of fire ecology and succession in a mixed-conifer forest. Ecology 65:1725-1742.

Kienast, F. 1987. FORECE - A forest succession model for southern central Europe. Oak Ridge National Laboratory, Oak Ridge, Tennessee, ORNL/TM_10575, 69 pp.

Little, E. L. 1971. Atlas of United States Trees, 1. Conifers and Important Hardwoods. Misc. Publ. 1146, USDA Forest Service, Washington D.C.

Max, T. A., H. T. Schreuder, J. W. Hazard, D. D. Oswald, J. Teply and J. Alegria. 1996. The Pacific Northwest Region Vegetation and Inventory Monitoring System. USDA Forest Service, PNW Res. Sta. Res. Pap. PNW-RP-493. Portland, OR.

Monsi, M. Uchijima, Z., and Oikawa, T. 1973. Structure of foliage canopies and photosynthesis. Ann. Rev. Ecol. and Syst. 4:301-327.

Noble, I. R., H. H. Shugart and J. S. Schauer. 1980. A Description of BRIND, a Computer Model of Succession and Fire Response of the High Altitude Eucalyptus Forests of the Brindabella Range, Australian Capital Territory. ORNL/TM_7041, Oak Ridge National Laboratory, Oak Ridge TN. 96 p.

Pastor, J. & Post, W. M. 1987. Response of northern forests to CO2_induced climate change. Nature 334:55-58.

Prentice, I. C., Cramer, W., Harrison, S.P., Leemans, R., Monserud, R. A. & Solomon, A. M. 1992. A global biome model based on plant physiology and dominance, soil properties and climate. Journal of Biogeography 19:117-134.

Prentice, I. C., M. T. Sykes and W. Cramer. 1993. A simulation model for the transient effects of climate change on forest landscapes. Ecological Modelling 65: 51-70.

Shugart, H. H. 1984. A theory of forest dynamics. The ecological implications of forest succession models. Springer, New York, 278 pp.

Schumaker, N. H. 1998. A Users Guide to the PATCH Model. EPA/600/R_98/135. USEPA, Corvallis OR., 120 p.

Solomon, A. M. 1987. Use of stand models at varying spatial scales to simulate forest responses to environmental changes. In: Seymour, R.S. & Leak, W.B. (eds.), Proceedings of the New England Growth and Yield Workshop. Miscellaneous Report 325, Maine Agriculture Experiment Station, Orono, ME, 46-58.

Solomon, A. M. & Bartlein, P. J. 1992. Past and future climate change: response by mixed deciduous-coniferous forest ecosystems in northern Michigan. Canadian Journal of Forest Research 22:1727-1738.

Solomon, A. M. and D. C. West. 1993. Evaluation of stand growth models for predicting afforestation success during climatic warming at the northern limit of forests. p. 167 188 IN R. Wheelon, ed. Forest Development in Cold Regions. Proceedings, NATO Advanced Research Workshop. Plenum Publ. Corp., NY.

Thompson, R. S., K. H. Anderson and P. J. Bartlein. 1999. Atlas of Relations Between Climatic Parameters and Distributions of Important Trees and Shrubs in North America. USGS Prof. Pap. 1650 A&B. U.S. Geological Survey, Denver CO.

Urban, D. L., Harmon, M. E. & Halpern, C. B. 1993. Potential response of pacific northwestern forests to climatic change, effects of stand age and initial composition. Climatic Change 23:247-266.

Watt, A. S. 1947. Pattern and process in the plant community. Journal of Ecology 35:1-22.

Woudenberg, S. W. and T. O. Farrenkopf. 1998. The Westside Forest Inventory Data Base: User's Manual. http://www.srsfia.usfs.msstate.edu/wwman.htm.

Appendix 4

Quality Assurance Task Plan
for the
Model Linkages and Visualization Project

Version 1.3 *August 17, 2005*




1. TASK DESCRIPTION

1.1 • Overview and Objectives

Model Linkages A critical element of the Terrestrial Habitats Project is its strong emphasis on linking different environmental models to develop improved wildlife risk assessments. The use of existing models expands our analytic capacity but avoids the long development times necessary for creating entirely new models. Our individual models, previously applied at singular but overlapping scales, simulate (in ascending scale order) stand growth and community development (FORCLIM), ecosystem biogeochemistry (MBL-GEM), and regional wildlife population dynamics (PATCH). As a group, these models provide the starting point for modeling across scales to address risk assessment problems that do not yield to traditional reductionist approaches. This initial set of models and linkages addresses a broad array of risk assessment goals in forest and agricultural landscapes, as illustrated by the case studies described in the project research plan. Both forested and agricultural landscapes are highly managed and often subjected to intensive pesticide use. Wildlife occupying such landscapes are subjected to multiple natural and anthropogenic stresses, and thus risk assessments targeting pesticide use (for example) must control for all such impacts and interactions. Our procedures for creating the model linkages outlined in this QATP will result in risk assessment methodologies that are better able to address multiple interacting stressors in large landscapes.

Data Visualization The models, databases, and linkages described above target current and future research and management issues involving wildlife populations and their habitats. However, until our solutions can be communicated to other scientists and managers, the problems themselves will never be solved. For this reason, we intend to incorporate computer visualization software into our modeling toolkit. In addition to communication of results, such software can speed the development of models and modeling solutions by helping researchers to quickly interpret their results. While viewing results in a numerical form can provide insights, the quantity of data produced by our linked model simulations will make this task cumbersome at best, and impossible at worst. To make these data easier to analyze, we will apply existing visualization software package to convert the numerical data into pictures and animations. This approach is analogous to exploratory data analysis (EDA), a method predicated on the idea that the human eye and brain excel at pattern recognition (Tukey 1977).

Taken together, our linked models and visualization capabilities will establish a new methodology for higher tiered terrestrial risk assessments that is spatially explicit and designed for use in real settings. It will track conditions in ecosystems of concern over time frames that are ecologically relevant, and will provide the tools for assessing impacts on wildlife populations from multiple interacting natural or anthropogenic disturbances. The outputs will be computer-generated visualizations of predicted changes that can provide risk managers with real tools for use in environmental decision making.

1.2 • Products and Timetable

The principal products of this project will be a set of linked modeling tools – MBL-GEM, FORCLIM and PATCH – with associated visualization software that will enable quantitative projections of wildlife habitat and populations in response to multiple stressors in agricultural and managed forest landscapes. Development of the individual models and subsequent linkages will occur during years 1-3 (see Model Development QATPs), with landscape-scale applications to follow in years 4-5.

The APMs associated with this Task are listed in the Project's QAPP, in Table 3. A timeline for this Task is illustrated in the Project's QAPP, in Figure 1.

1.3 • Project Personnel

This task will be led by Dr. Robert McKane, Dr. Nathan Schumaker and Dr. Allen Solomon, the principal investigators responsible for development of MBL-GEM, PATCH and FORCLIM, respectively.

1.4 • Support Facilities and Services

Figure 1 lists the support facilities and services needed to carry out specific tasks for this task. EPA-WED computing resources are already available. EPA support for visualization resources will be needed for the duration of the project.

Table 1. Support Facilities for the Forested Landscapes Case Study

Support Facilities and Services	Associated Tasks
EPA-WED Computing Resources	Simulation of Wildlife Habitat and Populations
EPA Scientific Visualization Center	Visualization of Model Output

2. Model Description

2.1 • Model Overview

Linking Wildlife and Plant Community Models

The kinds of linkages that are necessary can be best understood by examining the individual models we will employ, and the goals associated with our unique applications. The wildlife population model (PATCH), for example, is being developed to provide accurate projections of chemical and non-chemical stressors on wildlife species. This goal in turn requires information on community structure (species composition and three-dimensional properties) of habitats on which wildlife depends, and on the responses of that structure to changing forces that are both internal (plant succession, interspecies competition, pest attacks) and external (climate change, fire and land use disturbance, pesticide use) to the habitats. Therefore, we propose to link PATCH to FORCLIM, a process-based plant community model that simulates annual stand-level changes in forest growth and 3-dimensional community development, including responses to stressors of concern for wildlife endpoints.

The goal of linking FORCLIM to PATCH is to permit PATCH to calculate the responses of wildlife populations to environmental stressors that affect wildlife indirectly by changing their habitat. The approach is to provide more detailed, realistic and dynamic simulated habitat to replace the unchanging habitat classes currently used in PATCH. FORCLIM also will be extensively modified to provide the specific variables needed to implement more accurate projections of wildlife population responses to environmental stressors by PATCH (see QATP for FORCLIM Model Development).

Linking Biogeochemistry and Plant Community Models

To further improve the initial predictions of a FORCLIM-PATCH linkage, we will link FORCLIM to MBL-GEM, a biogeochemistry model that includes a more process based treatment of multiple stressor effects on ecosystem C, N and water dynamics. Application of MBL-GEM will significantly improve estimates of plant-available soil nitrogen and water that mediate the changes in plant species establishment and succession simulated in plant community models.

Thus, the linkage of MBL-GEM and FORCLIM will replace weaknesses inherent to each class of models with the strengths of the others. While the strength of FORCLIM is its mechanistic representation of changes in plant species establishment and succession as a result of natural or anthropogenic stress, it (and all other community models) uses more simplified, empirical approaches for simulating changes in the availability and allocation of growth-limiting resources such as carbon, water, and nitrogen. In contrast, MBL-GEM is designed to mechanistically describe the processes controlling growth-limiting resources and how they respond to important stressors, but does not address the consequences of these changes on plant species composition or community structure. Given the strong water and/or nitrogen limitation to vegetation growth and establishment in the Pacific Northwest, this linkage can significantly improve the accuracy of our predicted changes in habitat quality and, ultimately, PATCH's assessment of changes in wildlife populations.

Visualization of Model Output

The implementation of these software packages will require the combined use of geographic information systems (GIS), numerical model output, and digital imagery. EPA's High Performance Computing & Scientific Visualization group in Research Triangle Park, NC will provide essential contract support for this task. Specific visualization methods will be developed as the project progresses, but will likely involve the following steps (Dunbar et al. 2003):

- Integration of software with geo-referenced GIS datasets for the case study areas.
- Development of land cover types using defined ìhabitatî types.
- Use of raster and/or vector formats to drive rendered vegetation components.
- Development of static and animated time-series habitat visualization at the plot- and landscape scales.

2.2 • Model Parameters

A description of the model parameters for each of the models to be linked is provided under the model development QA plans for PATCH, GEM and FORCLIM (see Appendices 1, 2 and 3, respectively, sections 2.2).

2.3 • Computer Aspects

Model Linkages Because all of the models we discuss are constructed in modular form demanded by their programming languages (FORTRAN 94; C++; PASCAL), the linkages themselves are conceived as simple exchanges of model output, primarily on an annual (occasionally seasonal or daily) basis, after each variable is transformed to the data input format required by the acceptor model. This loose coupling will permit development of each model to continue unimpeded by rates at which the other models are being modified.

Data Visualization Many commercial visualization software packages exist, and the disparate goals of our case studies may require several different programs. We have begun exploratory discussions with EPAís High Performance Computing & Scientific Visualization group in Research Triangle Park, NC to select the visualization packages most suited for our project goals. Two software packages appear to be very promising -- *Visual Nature Studio (VNS)* produced by 3D Nature, Ltd., and *EnVision* produced by the U.S. Forest Service. Both packages are designed to be full-featured rendering systems for stand- and landscape-scale images at scales ranging from one to thousands of hectares. An advantage of *VNS* over *EnVision* is that it is capable of representing temporal changes in habitat.

2.4 • Data Sources and Quality

Accurate simulation of wildlife habitat and populations by the linked models will require careful collection and analysis of project data. The SOPs and DQOs listed in the project case study QATPs will establish quality assurance and quality control procedures to help ensure that simulated habitat and wildlife characteristics are real and not due to bias, sampling error or measurement error. Simulation protocols and characterization of uncertainty by the linked models will also follow the procedures described in those QATPs.

All staff involved with model simulations, and sample collection and analysis will be required to follow project SOPs. Staff will be trained on proper collection, processing and storage of plant, soil, meteorological and wildlife samples and data, and model applications. As part of their training, personnel will be given any relevant SOPs and required to follow them for the duration of the project.

2.5 • Data Management

A large amount of model output will be generated during the course of the model linkage and visualization tasks. Principal Investigators conducting simulations will store input and output files as electronic files with backup copies. Custody of raw data files will be with the Principal

Investigators. For contractor-generated visualization data, electronic copies of output files will be routed with a summary report to the Work Plan Manager who will in turn send it to the Work Assignment Manager.

3. MODEL DEVELOPMENT

3.1 • Code Development and maintenance

No new code will be developed to link GEM, FORCLIM and PATCH. The model linkages will simply require reformatting the output from one model (e.g. daily changes in leaf area predicted by GEM) to serve as input for another model (e.g., FORCLIM). Text files will generally be used for the reformatting process, and in some cases may include conversion of daily data to monthly means. A complete description of model code development and maintenance for the individual models is provided under the model development QA plans for PATCH, GEM and FORCLIM (see Appendices 1, 2 and 3, respectively, sections 3.1).

3.2 • Model Documentation

Model documentation procedures are provided under the model development QA plans for PATCH, GEM and FORCLIM (see Appendices 1, 2 and 3, respectively, sections 3.2).

3.3 • Code Verification

Code verification procedures are provided under the model development QA plans for PATCH, GEM and FORCLIM (see Appendices 1, 2 and 3, respectively, sections 3.3).

3.4 • Code Documentation

Code documentation procedures are provided under the model development QA plans for PATCH, GEM and FORCLIM (see Appendices 1, 2 and 3, respectively, sections 3.4).

4. Model Application

4.1 • Model Calibration

GEM, FORCLIM and PATCH will be calibrated prior to linking the models, using the calibration procedures described under the model development QA plans for PATCH, GEM and FORCLIM (see Appendices 1, 2 and 3, respectively, sections 4.1).

4.2 • Model Validation

We expect the linkage of GEM and FORCLIM to result in improved habitat predictions compared to the individual, unlinked models. The success of the linked models will be assessed using the same validation procedures described for the unlinked models – see the model development QA plans for PATCH, GEM and FORCLIM, Appendices 1, 2 and 3, respectively, sections 4.2.

4.3 • Model Uncertainty

All physically-based models have uncertainty in their output, so it is important to quantify how uncertainty is propagated from one model to another when they are linked. We will do this through an error analysis in which input to a receptor model is sampled from the range of output from a source model. That is, repeated runs of the source model, each with a different set of parameters drawn from the sampling distribution (95% confidence intervals), will be used to produce a distribution of model outputs that reflects the uncertainty in the parameter estimates (Pacala et al. 1996). To identify robust wildlife habitat and population predictions, we will present the results of several series of simulations in which uncertainty is propagated from MBL-GEM to FORCLIM to PATCH.

5. Assessment and Oversight

5.1 • Monitoring

Dr. Robert McKane will provide overall oversight for the model linkage and visualization tasks. The principal investigators responsible for each of the primary modeling components will periodically review the status of all datasets and model software for integrity and completeness: Dr. Robert McKane for MBL-GEM; Dr. Allen Solomon for FORCLIM; and Dr. Nathan Schumaker for PATCH. These reviews will occur both when problems are suspected and in random inspections.

5.2 • Reporting

The primary form of reporting for this project will be manuscripts and reports describing results of investigations. This reporting will include considerations of data quality and model uncertainty discussed in the preceding sections.

6. References

Pacala, S. W., C. D. Canham, J. A. J. Silander, R. K. Kobe, and E. Ribbens. 1996. Forest models defined by field measurements: Estimation, error analysis and dynamics. Ecological Monographs, 66:1-43.

Tukey, J. W. 1977. Exploratory Data Analysis. Addison-Wesley, Reading, MA.

Appendix 5

Quality Assurance Task Plan
for the
Agricultural Landscapes Case Study

Version 1.3 *August 17, 2005*




1. TASK DESCRIPTION

1.1 • Overview and Objectives

Our case study devoted to agricultural landscapes will be conducted in two parts. The first is a conceptual study being designed in close consultation with scientists from the Environmental Fate and Effects Division (EFED) of EPA's Office of Prevention, Pesticides, and Toxic Substances (OPPTS). This modeling effort is led jointly by Dr. Nathan Schumaker and Dr. Richard Bennett of the Mid-continent Ecology Division (MED). This study is tightly coupled to the PATCH development work described above, will involve parameterizing the model for several bird life histories, and will examine a hypothetical suite of agricultural landscapes and stressors. This work will demonstrate our overall modeling approach to higher-tier wildlife risk assessments. The second part of the agricultural landscape case study is an empirical test of our approach in a real setting, using a bird species that is being exposed to multiple real stressors. This work will focus on western bluebird (*Sialia mexicana*) and agricultural areas within Oregon's Willamette Valley. The work with bluebirds is being led by Dr. Laura Nagy. This work will generate critical parameter estimates, and serve as a validation study for the PATCH model. The two parts of the agricultural landscapes case study will be conducted concurrently.

Historically, pesticide risk assessments have focused on impacts to individual animals, and have estimated only those effects caused by direct toxicity following exposure. However, EPA's Office of Pesticide Programs (OPP), through a co-operative effort with industry and other stakeholders, has been challenged to "develop and validate risk assessment tools and processes that address increasing levels of biological organization, such as populations, communities and ecosystems" (US EPA, 1999). Despite this interest in scaling up from the level of the individual, an acceptable methodology with which to do so is not currently available. Further, any useful methodology must capture the interactive effects of pesticide toxicity, natural environmental variability, and landscape change (resulting from agriculture in this case). This Case Study will demonstrate how PATCH can serve as a useful tool to address both the scaling from individual to population responses, and the assessment of the cumulative effects of pesticide use and dynamic landscape change.

Much of the land within the contiguous United States is under some form of agriculture (~52%, USDA 1992), and is also used as both breeding and feeding habitat by many bird species (Best et al. 1995). Birds breeding in agricultural settings are faced with multiple stressors, some that are unique to agriculture such as the large-scale application of pesticides (insecticides and herbicides) and mowing and harvesting, and others that are faced by most bird species, such as landscape fragmentation and natural environmental stochasticity. At any given location, birds can be exposed to an array of stressors, both natural and artificial, and this disturbance matrix will change as they move over the landscape. Accurately projecting bird population dynamics thus requires integrating stressors across multiple spatial scales.

The presence of multiple disturbances means that risk assessments designed to anticipate changes in population dynamics due specifically to pesticides must evaluate the relative importance of each relevant stressor. The relative importance of a stressor will be determined by how it interacts with other factors to influence survival and reproduction. Such interactions could range from stressors negating each other and thus minimizing the impact on a wildlife population, to stressors compounding each other to produce a larger cumulative impact. Despite the critical role such interactions could have on survival and reproduction; currently, little, if any, information exists about the interactions among stressors. Further, birds have the capacity to make decisions and may respond in a variety of ways to different stressors. The presence of a stressor may initiate a behavioral response such as a shift in foraging patterns, or abandonment of a nest site. Such behaviors could occur within a single breeding season or between breeding season. By moving, a bird may be able to increase the probability of having a successful breeding attempt, or improve the likelihood that it will survive to breed the following year.

The agricultural landscapes case studies will demonstrate our integrative risk assessment methodology and allow EFED to evaluate its potential to meet their needs and couple with their individual-based toxicological assessments. Our development and application of spatial models to questions about population effects will help EFED's scientists, risk assessors, and managers explore the long-term population consequences of pesticide exposure and other stressors in birds with different life history strategies, and evaluate the relative importance of mortality and reproductive effects. Furthermore, this approach will provide a tool for landscape-scale assessments to identify pesticide application regimes that minimize risks to wildlife populations, or provide insight for mitigating measures that might be instituted as a registration requirement.

1.2 • Products and Timetable

Our goal is to demonstrate the use of population and spatial modeling tools that can put projections of pesticide effects on individual birds into the context of population-level effects and different land-use patterns. When questions concern the significance of projected mortalities from insecticide-treated fields to bird populations, they can not be answered simply from an assessment that considers only treated fields or only one pesticide at a time. A variety of crop types involving applications of many different compounds may occur within the geographical area that bounds a defined wildlife population. Some individual birds may not be exposed to any chemicals, while others may be exposed to a single pesticide on a single crop, and still others from the same population are exposed to two or more pesticides from different fields and/or different crops. Projected effects of pesticides on bird populations must emerge from an integration of effects on individuals within the population experiencing a wide diversity of exposure scenarios.

We will work simultaneously at a conceptual level, and through a detailed field experiment, to examine the response of population projections to model inputs, and to identify information gaps. EFED has shown in their case study with ChemX that risk projections vary with application rate and method, bird diet, food consumption rates, field use patterns (i.e., habitat use), and assumptions about species sensitivity. One likely outcome of this work will be the identification of types of required information that have not been used historically in pesticide risk assessments. In addition, this case study will examine how projections of risks to populations vary with differences in species life histories and landscape characteristics, such as cropping patterns (e.g., proportion of landscape consisting of corn, alfalfa, and others; field sizes; etc.), proportion of crops treated with ChemX and other pesticides, and spatial patterns and extent of non-crop habitat.

Scaling risk assessments from individual-levels up to populations requires developing an understanding of several complex issues. Our goal in this research is to better understand how landscape structure, species' vital rates and movement strategies, and natural variability interact to make species more or less vulnerable to pesticides. To this end, we construct a coarse conceptual diagram for the species-landscape-stressor system and pose four focal questions:

1. How sensitive are population-level assessments of pesticide exposure to errors in estimates of species' vital rates, movement behaviors, and natural environmental variability?
2. How do anthropogenic stressors and natural variability interact to influence population dynamics?
3. What are the consequences of ignoring an individual's history of exposure to pesticides?
4. How do organisms use movement to respond to stressors in their environment, and how do such movements alter population dynamics?

The agricultural landscapes case study consists of two components designed to complement each other. A conceptual study will examine four bird species, but will only attempt to approximate their life histories. It will employ hypothetical computer-generated landscapes that have some realistic properties. This study will simulate crop rotation and the application of a single semi-realistic chemical stressor. The goal of the conceptual study is to generate a proof of concept illustration of our methodology that better guides future interactions with our EPA clients. We will also develop an empirical study that focuses carefully on a single bird species occupying real landscapes in which an array of complex stressors all interact and influence population growth rates. This study will illustrate how our methods can be applied by risk assessors in real-world settings where stochasticity, complexity, and data shortages limit our ability to conceptualize and quantify system dynamics. The goal of the empirical study is to gather data necessary to conduct a validation of the PATCH model as a tool for performing probabilistic wildlife risk assessments, and to guide future model enhancements.

The APMs associated with this Task are listed in the Project's QAPP, in Table 3. A timeline for this Task is illustrated in the Project's QAPP, in Figure 1.

1.3 • Project Personnel

Our conceptual study will be led by Dr. Nathan Schumaker. Collaborators will include Dr. Donald Phillips and Dr. Rick Bennett (MED). Our empirical study will be led by Dr. Laura Nagy.

1.4 • Support Facilities and Services

Our conceptual study has no requirements for facilities or services beyond the computing infastructure and the Federal and non-Federal staff already available to the project. Our empirical study has the added need of minimal workspace for the fabrication and maintenance of bird houses, and similar tasks. These facilities have already been made available to the project.

2. METHODOLOGY

2.1 • Experimental Design

Conceptual Study Our overall approach is to use PATCH to examine effects of agricultural pesticides on the sustainability of avian populations through a series of contrasting land-use and pesticide-use scenarios. Representative avian species will be selected from among those currently being used in EFED's case studies. Next, representative agricultural landscapes will be developed based on land-use statistics for regions of interest, that simulate the types and proportions of crops grown, and pesticides applied, in each region. Third, for the selected avian species, life history parameters (including survival and fecundity rates, dispersal distances, and site fidelity) and habitat suitability information will be synthesized from existing datasets to develop spatially-explicit population predictions using the PATCH model. Finally, estimated mortality rates for birds exposed to ChemX (derived from the EFED case study; Fite et al. 2001) will be used to modify survival rates for individual birds on the proportion of crop fields that are treated. Different assumptions about land-use and pesticide-use patterns will be examined with the model, and their effects on bird population trends through time and space will be compared.

Empirical Study Our experimental design has been structured to facilitate our successfully completing the following three focal tasks:

1. To determine survival, reproduction, and nestling growth rate of Western Bluebirds in a variety of agricultural settings that encompass different anthropogenic and natural stressors.
2. To determine movement patterns of Western Bluebirds, both within and between breeding seasons in response to disturbance and nesting success.
3. To determine energy expenditure and habitat use of Western Bluebirds in a variety of agricultural settings.

This research will be conducted on a minimum of 100 nest boxes that are located within the greater Corvallis, Philomath, Albany area. Boxes will be placed so that they covered a variety of land use types, including, but not limited to grass fields, tree farms, wildlife refuges, pasture, and vineyards. Boxes will be placed in areas where Western Bluebirds are known to breed and we will try to distribute boxes as evenly as possible across different land types. Nest box locations will be recorded using a global positioning system (GPS - Garmin etrex). Generalized habitat type is defined based on the primary land-use within 100 m of the nest box. Habitat use by the birds will be defined by the territory used by the birds and specific definitions will be created after collecting some preliminary data.

Our research questions will be analyzed using general linear models. These models will control for different habitat types (grassland, vineyard, residential, natural, tree farms, pastures, other), age of the birds (1st breeding year or older) where both of these factors are treated as categorical variables. In addition, data on reproductive success will be collected on violet-green swallows and tree swallows, as these species also use nest boxes and utilize the same habitat types. These data will be used to evaluate if trends in reproductive success of western bluebirds across habitats is species-specific or can be generalized.

2.2 • Measurement and Data Acquisition

Conceptual Study For this demonstration, four species have been selected from the original list of representative avian species used by EFED (Fite et al. 2001) – horned lark (*Eremophila alpestris*), mourning dove (*Zenaida macroura*), vesper sparrow (*Pooecetes gramineus*), and meadowlark [combined eastern (*Sturnella magna*) and western (*S. neglecta*) meadowlark]. However, our goal is not to accurately simulate any single species, but instead to compare and contrast life history strategies that approximate the species listed above. Estimated mortality distributions and supporting life history information exist for these birds (Fite et al. 2001), and all four species are found in the midwestern agricultural habitats that are the subject of this study (Table 1).

Differences in nesting site preferences for these four species illustrate some of the issues involved in characterizing suitable habitat in agricultural landscapes. Horned larks prefer to nest in open, sparsely vegetated areas such as row crops, which can be abundant in an agricultural landscape. However, mourning doves prefer to nest in small trees, that exist most often in narrow strips such as wooded fencerows, shelter belts, residences, and some riparian areas. Meadowlarks and vesper sparrows may also nest in fencerows, roadsides, and grassy waterways, though both use pastures and hayfields and vesper sparrows will nest in row crops.

Table 1. Habitat Preferences, Feeding, and Nesting Sites

Species	Diet Preference	Feeding Sites	Nesting Sites
Meadowlark	Insectivore	Pastures, Row Crops, Hayfields, Waterways, Herbaceous Fencerows	Pastures, Alfalfa, Other Hay, Waterways, Herbaceous Fencerows
Horned lark	Omnivore	Pastures, Row Crops, Fallow Fields	Pastures, Row Crops, Fallow Fields
Vesper sparrow	Omnivore	Pastures, Row Crops, Alfalfa, Other Hay, Waterways, Herbaceous Fencerows	Pastures, Row Crops, Alfalfa, Other Hay, Waterways, Herbaceous Fencerows
Mourning dove	Granivore	Pastures, Row Crops, Hayfields, Shelter belts, Residences, Wooded Fencerows	Shelter belts, Residences, Wooded Fencerows

Representative landscape maps will be developed using detailed maps of actual agricultural areas that include the desired landscape attributes. Aggregate landscape properties will be measured from the real maps and used to construct sequences of hypothetical images that illustrate different land use change scenarios. For example, we might begin with a map of a specific location including attributes such as major roads, urban and rural residential sites, rivers, forests, and agricultural areas. Then the map would be modified by creating an "agricultural land" classification that is divided into a grid of rectangles representing hypothetical agricultural fields. Each field within the grid could then be assigned to a specific crop type. The types of crops, and proportion of each crop, would be set to reflect the conditions in the landscape of interest. Crop rotations could be easily simulated by changing the spatial arrangement of field types while fixing the locations of all other map attributes.

This demonstration will focus on agricultural landscapes that are representative of two regions of the country where corn is a dominant crop: north-central Iowa and south-central Pennsylvania. Both are important corn-growing areas within their states, but they differ in many landscape attributes. Information about the types and proportions of major crops grown in these areas is summarized in the U. S. Census of Agriculture in 1997 for Iowa (USDA 1997a) and Pennsylvania (USDA 1997b). A pilot study has already been conducted for Franklin, Hardin, Hamilton, and Wright Counties in north-central Iowa and Lancaster and York Counties in south-central Pennsylvania. The relative proportions for major crops were estimated by aggregating agricultural statistics from these areas. Of the approximately 600,000 ha of land in the four counties in north-central Iowa, 94% is in farms, with 93% of farmland in various crops. Approximately 1% of farmland is forested, and 4% is occupied by houses, roads, ponds, and wasteland. By comparison, 55% of the 480,000 ha of land in two counties in south-central Pennsylvania is in farms, with 84% of farmland in various crops. Approximately 4% of farmland in this portion of Pennsylvania is forested, and 2% is occupied by houses, roads, ponds, and wasteland. Approximately half of all cropland in both the Iowa and Pennsylvania sites is planted to corn. Almost a third of the cropland in Pennsylvania is in alfalfa, others hay crops, or small grains, compared to only about 1% in Iowa (Table 2) These agricultural statistics can then be used as a guide in developing representative landscape maps. Non-crop areas adjacent to fields are extremely important for many species in determining abundance and distribution. Bird activity is often significantly higher on the edges of row crop fields and in adjacent cover than in the centers of fields. However, the types of bird species using adjacent cover as well as the overall numbers of birds is affected by whether patches of cover are herbaceous or woody.

Table 2. Proportion of Cropland Planted to Various Crop Types

Cropland Type	Representative of North-Central Iowa	Representative of South-Central Pennsylvania
Corn (field and sweet corn)	51%	47%
Soybeans & other row crops	45%	13%
Alfalfa	0.7%	11%
Other hay and pasture	0.4%	12%
Small grains	0.2%	10%
Orchards	0%	1%
Other crop types	3%	7%

Our goal here is to contribute to an EFED study that examined the impact to birds of carbofuran, a cholinesterase-inhibiting insecticide/nematicide. The 1997 Census of Agriculture for Iowa (USDA 1997a) indicates that carbofuran was used on 2% of corn and 3% of alfalfa. In Pennsylvania in 1997, carbofuran was used on 3% of field corn, 10% of sweet corn and 9% of alfalfa (USDA 1997b). In 2001, carbofuran was applied to less than 1 percent of all corn in the United States (USDA 2002). In this work, we will use the 1997 percentages for carbofuran-treated acreage in the PATCH simulations.

Insecticides were applied to 60% of all corn acreage in Pennsylvania during 2001, with chlorpyrifos (another cholinesterase-inhibiting insecticide) used on 30% of corn. Many of the synthetic pyrethroid insecticides used on corn do not present an acute toxicity risk to birds, but over half of the treated corn acres were treated with organophosphorus or carbamate insecticides. Most of these insecticides are not as acutely toxic to birds as carbofuran, so this case study will use simulations that assume higher rates of combined usage of cholinesterase-inhibiting insecticides to examine possible cumulative effects on bird populations.

Dr. Rick Bennett (NHEERL/MED) estimated life history parameters for mourning doves, horned larks, vesper sparrows, and eastern and western meadowlarks based on information present in the Birds of North America series, a literature review performed as part of WED’s APM 150 (FY2002), and other sources. Dr. Bennett’s estimates of juvenile and adult survival, fecundity, territory size, and dispersal distance are displayed in Table 3. Survival was expressed as the proportion surviving from one year to the next. Fecundity was expressed as the number of female offspring produced per adult female per year. Values for average territory size were expressed in hectares. Dispersal distance was expressed in kilometers.

Empirical Study The following types of data collected activities will be performed in the process of completing this Task. These data will all be collected by Project personnel at field sites that have already been identified.

- Nest checks
- Measuring and banding nestlings
- Foraging behavior
- Fledgling observations
- Resighting western bluebirds

3. Quality Control and Assurance

3.1 • Equipment and SOPs

Five SOPs have been developed for the empirical research components of this task. These SOPs are available on the local network at *X:\Projects\Bluebird Project\Protocols\2005 protocol\Original SOPs* with signed cover sheets. The equipment being used to conduct this task is described in the SOPs.

3.2 • Quality Control

<u>*Conceptual Study*</u> No original data will be developed for this study. To ensure integrity, we will parameterize our models with data obtained from the peer-reviewed literature, or from sources for which the quality is known.

Table 3. Estimated Mean Life History Parameters for Four Avian Species

Species	Juvenile Survival	Adult Survival	Adult Fecundity	Territory Size (hectares)	Dispersal Distance (km)
Meadowlark	0.16	0.53	1.25	2.37	0.96
Horned lark	0.40	0.51	1.58	1.60	1.00
Vesper sparrow	0.40	0.53	1.45	2.27	1.00
Mourning dove	0.44	0.53	1.80	0.80	17.8

Empirical Study Data will be gathered following the SOPs for nest checks, resighting western bluebirds, measuring and banding nestlings, foraging behavior, and fledgling observations (Table 4). To ensure that these standards are followed, Dr. Nagy will evaluate the incoming data every 1 to 3 days to ensure that 1) the correct data is being collected, 2) the data is collected at the correct time intervals relative to the breeding cycle, and 3) data entry is correct and prompt following these QC protocols. During the life of the project, a minimum of one QC audit will be performed.

3.3 • Quality Assurance

Conceptual Study The goal of this study is to demonstrate the feasibility of our methodology to EFED. This will not require the precise estimation of any bird population sizes, trajectories, or distributions. The QA/QC to be performed on the PATCH model will ensure that our results do not contain errors attributable to coding mistakes. In addition, we will explore the dependence of our results on the precise model parameterizations used in the study.

Empirical Study The protocols we will use to ensure data quality are detailed in Table 5. Each set of measures will be replicated in a variety of land uses and each land use type will have >1 site, thus allowing us to determine the representativeness of the data. To maximize completeness, we have set bluebird boxes in most of the predominant land-types in the Willamette Valley including grass fields, vineyards, pasture, and natural and residential areas.

3.4 • Data Management

Conceptual Study There are no significant data management issues associated with the conceptual study.

Table 4. Data Characteristics

Parameter	Units	Expected Range (WEBL)	Expected Range (TRSW)	Expected Range (VGSW)	Accuracy	Precision
Number Eggs	Egg	1-7	1-7	1-7	100%	100%
Number Nestlings	Nestling	1-7	1-7	1-7	100%	100%
Number Fledglings	Fledgling	1-7	1-7	1-7	100%	100%
Nestling Weight on Day 4	Grams	5-15	N/A	N/A	± 0.1 g	± 0.1 g
Nestling Weight on Day 8	Grams	10-20	N/A	N/A	± 0.1 g	± 0.1 g
Nestling Weight on Day 12	Grams	10-30	N/A	N/A	± 0.1 g	± 0.1 g
Tarsus on Day 4	Millimetres	7-15	N/A	N/A	± 1 mm	± 1 mm
Tarsus on Day 8	Millimetres	10-21	N/A	N/A	± 1 mm	± 1 mm
Tarsus on Day 12	Millimetres	15-23	N/A	N/A	± 1 mm	± 1 mm
Bill Length	Millimetres	6-12	4-8	4-8	± 1 mm	± 1 mm
Out-of-Pin	Millimetres	0-15	5-20	0-10	± 1 mm	± 2 mm
Habitat Characterization	% Landuse	Varied	N/A	N/A		± 5%
Female Time Budget	% Time Foraging	40-80%	N/A	N/A		± 10%
Territory Size	Hectares	0.2-0.8	N/A	N/A		± 0.1 ha
Fledgling Dispersal Distance	Meters	1-1000	N/A	N/A	20 m	± 5 m

Empirical Study Several types of data will be collected in the process of completing this Task, including reproduction and survival rates, nestling weights, foraging patterns, habitat use, and fledgling movements. The data management concerns for each category are discussed below:

Table 5. Calibrations

Instrument	QA Check	Frequency	Data Summary	Acceptance Criteria	Action if Unacceptable
Digital Calipers	Compare with NIST standard ruler	Yearly	Single Measure	≤ 0.1 mm	Clean, Adjust, or Repair
Ohaus Balance	Compare with NIST standard ruler	Weekly	Single Measure	≤ 0.1 g	Clean, Adjust, or Repair
Pesola Spring Scale	Compare with NIST standard ruler	Weekly	Single Measure	≤ 0.1 g	Clean, Adjust, or Repair
Trained Observers	Test against selected expert	Bi-Weekly	Time per Behavior	≤ 5%	Retrain and Re-test

- Reproduction and Survival.

  Data will be entered onto nest cards and data sheets. Transcription into a central database will take place on the same day as data collection. This transcription will be proofed by someone other than the individual who observed on the day of data collection. Weekly error checking of the central database will performed. These checks will include scanning for inconstant chronologies, inconsistencies in the numbers of young in various developmental stages, errors in the recording of dates, nest status, and individual fates, and inconsistencies in color band data.

- Nestling Weights.

  Data will be entered onto nest cards and data sheets. Transcription into a central database will take place on the same day as data collection. This transcription will be proofed by someone other than the individual who observed on the day of data collection. Nestling weights will be assessed to make sure they are within normal ranges. Normal ranges will be determined over the course of the 1st breeding attempt, and then these values will be entered into the computer, so that any value that is 1.5 standard deviations away from the mean will generate a caution box.

- Foraging and Habitat Use.

  Data collection will either be collected verbally onto microcassettes or will be directly entered into a PDA (personal data assistant). If data is collected on microcassettes, it will be transcribed into the database within 1 month of data collection. If data is collected onto a PDA, it will be uploaded into a database on the same day it is collected.

- Fledgling Movement.

  Data collection will either be onto data sheets or directly into a gps unit. Data will be either entered into a database on the day it was collected or downloaded to the database on the day it was collected.

Data will be considered valid if the following are true:

- Clutch completion date $<$ hatching date $<$ fledging date.
- Number eggs $\leq$ Number nestlings $\leq$ Number fledglings.
- Data points are not statistical outliers (Statistical outliers will examined to determine if there is an error in the data collection/recording or if the data point is correct).

4. ASSESSMENT AND OVERSIGHT

4.1 • Monitoring

Dr. Nathan Schumaker and Dr. Laura Nagy will provide overall oversight for the conceptual and empirical portions of the Task, respectively. These investigators will periodically review the status of all software, datasets, and results for integrity and completeness. These reviews will occur both when problems are suspected and in random inspections.

4.2 • Reporting

The primary form of reporting for this project will be manuscripts and reports describing results of investigations. This reporting will include considerations of both data quality and model uncertainty.

4.3 • Model Uncertainty

The consequences of model uncertainty must be examined in situations where the PATCH model is used to draw conclusions about real populations, in real settings, that are exposed to real stressors. When one or more of these factors is hypothetical, then an examination of model uncertainty, while illustrative, becomes an academic exercise.

Our modeling work with bluebirds in Willamette Valley agricultural landscapes warrants an examination of the consequences of model uncertainty. However, the PATCH simulation model is complex and not well suited to either formal sensitivity analysis or formal propagation of errors. There are may inputs and parameters associated with the model, such as numerical species-habitat classifications or landscape structure, that are not amenable to these analytic methodologies.

However, we are gathering data on bluebird vital rates in various agricultural settings, and thus will be able to estimate ranges for these parameters. We will perform simulations using the mean values of these parameters, and compare these results to simulations that draw parameters from distributions that incorporate these ranges. For example, adult bluebirds nesting in grass plantations may, on average, produce three fledglings. But some such nests might produce as few as zero fledglings, while others may produce as many as five. We will compare simulations that use the mean value of three fledglings per nest (for each nest in a grass plantation) with simulations that determine the nest size by drawing from a distribution that has a minimum of zero, a maximum of five, and a mean of three. Such an analysis will illustrate the consequences of the variability that we know exists in the bluebird system, and will do so without making the unrealistic assumption that all individuals will experience the extremes in parameter values simultaneously.

5. REFERENCES

Best LB, Freemark KE, Dinsmore JJ, and Camp M (1995). A review and synthesis of habitat use by breeding birds in agricultural landscapes of Iowa. American Midland Naturalist 134:1-29.

Fite E, Odenkirchen E, Barry T (2001). A Probabilistic Model and Process to Assess Acute Lethal Risks to Birds. Office of Pesticide Programs. Report prepared for the FIFRA Science Advisory Panel Meeting, Washington, D.C., March 13-16, 2001 (http://www.epa.gov/scipoly/sap/2001/index.htm).

USDA (1992). Agricultural Statistics, 1991. United States Department of Agriculture, Washington, DC.

USDA (1997a). Census of Agriculture. Iowa State and County Data. Volume 1, Geographic Area Series. AC97-A-15. United States Department of Agriculture, Washington, D.C. (http://usda.mannlib.cornell.edu/reports/census/ac97aia.pdf).

USDA (1997b). Census of Agriculture. Pennsylvania State and County Data. Volume 1, Geographic Area Series. AC97-A-38. United States Department of Agriculture, Washington, D.C. (http://usda.mannlib.cornell.edu/reports/census/ac97apa.pdf).

USDA (2002). Agricultural Chemical Usage: 2001 Field Crops Summary. Ag Ch 1 (02)a. United States Department of Agriculture, Washington, D.C. (http://usda.mannlib.cornell.edu/reports/nassr/other/pcu-bb/agcs0502.pdf)

US EPA (1999). Ecological Committee on FIFRA Risk Assessment Methods (ECOFRAM) Draft Terrestrial Report. Available at http://www.epa.gov/oppefed1/ecorisk/terrreport.pdf.

Appendix 6

Quality Assurance Task Plan for the Forested Landscapes Case Study

Version 1.3 *August 17, 2005*

1. TASK DESCRIPTION

1.1 • Overview and Objectives

Problem

The Upper South Santiam Watershed (USSW) is a nearly 50,000 hectare forest landscape in the Willamette National Forest in Oregon's western Cascade mountains. The complex topography and forest cover provide habitat for a broad array of wildlife populations. The major stressor affecting these populations during the past century has been habitat alteration associated with forest management. Harvest of forest products, fire suppression, road construction and other management activities have altered essentially every part of the landscape, creating a mosaic of habitat types that is historically unique. While forest management will remain an important stressor during the next century, projected changes in climate (temperature and precipitation) and atmospheric chemistry (CO2 and nitrogen) will become increasingly important (National Assessment Synthesis Team 2000).

The interactive effects of these multiple stressors on the quality and distribution of wildlife habitat are largely unknown, making it difficult to predict how human activities at local to global scales will affect wildlife endpoints. Our ability to make these predictions currently is limited by lack of a modeling framework that can translate the effects of multiple, interacting stressors on ecosystem processes (biogeochemical cycles) to changes in habitat structure (species composition and spatial pattern) and, ultimately, to changes in wildlife populations.

Objectives / Hypotheses

Our objective is to develop and link several process-based simulation models to predict and assess how scenarios of forest management, climate, CO2 and nitrogen deposition may alter habitat quality and distribution in the USSW, and how those habitat changes will affect selected wildlife populations. We will initially focus this risk assessment on western bluebirds (*Sialia mexicana*) and northern spotted owls (*Strix occidentalis caurina*). These species occupy different portions of the landscape, respond to very different spatial scales of disturbance, and have very different habitat requirements and life histories.

We hypothesize that:

1. Forest management will have the greatest immediate effects on the habitat of these species (spotted owls and bluebirds), by positively or negatively affecting habitat quality and distribution. For example, positive effects may be achieved by forest thinning practices to accelerate formation of "old growth" structure for owls, or patch clearcuts and nitrogen fertilization can be used to establish clearings that are more suitable for bluebirds. Negative effects may include establishment of fragmented habitats that decrease feeding efficiency and fecundity.
2. Projected increases in temperature, CO2 and nitrogen deposition will affect short-term ecosystem function (seasons to decades), resulting in increased vegetation productivity on low elevation fertile soils, and decreased productivity on high elevation droughty soils.
3. Changes in climate will alter the spatial distribution and abundance of plant species over longer time scales (decades to centuries). These changes will most negatively affect subalpine meadows and high-elevation old-growth *Pseudotsuga* and *Abies* stands, likely influencing distribution and viability of spotted owl populations.
4. Forest management practices can be used to mitigate the effects of climate change on wildlife populations by altering the distribution of vulnerable habitat types. For example, threatened habitats currently managed for spotted owls can be shifted over decades and centuries to soils and landscape positions better suited for developing and maintaining old-growth habitat characteristics.

1.2 • Products and Timetable

The principal products of this case study will be quantitative projections of wildlife habitat and populations in an intensively managed forest landscape. A suite of modeling tools – MBL-GEM, FORCLIM and PATCH – will be developed to make these projections. Methods for assessing the uncertainty of model projections for this case study will follow the general methods described in the Quality Assurance Task Plan for the GEM Model Development, section 4.3 Model Uncertainty.

MBL-GEM is an existing biogeochemistry model (Rastetter et al. 1991, McKane et al. 1995, 1997a, 1997b, Rastetter and Kwiatkowski 2002). The model requires no further development with regard to structure and coding, but will need to be parameterized for Pacific Northwest forest ecosystems to meet the requirements of this case study. The parameterized model will produce spatially-explicit projections of changes in ecosystem biogeochemistry and hydrology in response to likely stressor scenarios. MBL-GEM will be initially calibrated and validated at the stand-level during years 1 and 2. Landscape-scale projections will occur during years 3-5. Output from MBL-GEM will be used to constrain FORCLIM simulations of plant community (habitat) dynamics.

FORCLIM is an existing plant community model (Bugmann and Solomon 1995, 2000) that will be further developed for the requirements of this case study. The model will produce spatially-explicit projections (maps) of changes in the species composition and vertical structure of wildlife habitat. These habitat maps will be produced during years 3-5 and will be used to drive the PATCH model simulations.

PATCH is an existing model that was developed as part of the EPA's Willamette Valley Ecological Research Consortium. The requirements of this case study necessitate that a number of improvements be made to the model. Future versions of PATCH will couple life history parameters associated with a wildlife species to habitat maps and an arbitrary number of interacting stressors. The principal results of the simulations will be quantitative projections of population trends and distribution. Standard model outputs will include population size and structure, estimates of population viability, and mean movement distances. Results that are more unique to PATCH will include maps of habitat quality, population density, birth and death rates, and immigration and emigration rates, all of which change through time. We will also be able to examine the likely impact of changes to the severity, distribution, or timing of habitat alterations, climate change, or other stressors. The PATCH model design will permit these types of analyses to be conducted using actual landscapes and realistic suites of natural and anthropogenic stressors. Model development will occur during years 1-3. Simulation products will follow in years 4-5.

The APMs associated with this Task are listed in the Project's QAPP, in Table 3. A timeline for this Task is illustrated in the Project's QAPP, in Figure 1.

1.3 • Project Personnel

This case study will be led by Dr. Robert McKane. EPA collaborators include Dr. Nathan Schumaker, Dr. Allen Solomon, Dr. Peter Beedlow, Dr. William Hogsett, Dr. Mark Johnson, Dr. E. Henry Lee, Dr. Donald Phillips, Dr. David Tingey, Ronald Waschmann and Constance Burdick. Other collaborators include Dr. Edward Rastetter (Marine Biological Laboratory), Bonnie Kwiatkowski (Marine Biological Laboratory), Dr. Richard Busing (USGS), Dr. Mark Stieglitz (Columbia University), and Doug Shank (U.S. Forest Service).

1.4 • Support Facilities and Services

Table 1 lists the support facilities and services needed to carry out specific tasks for this study. EPA-WED laboratory facilities have already been made available. Work on GIS database development will occur during years 1-4. Visualization resources will be needed for the duration of the 5-year project.

2. METHODOLOGY

2.1 • Experimental Design

Our experimental design is structured to successfully complete the following three focal tasks for a managed forest landscape in the Upper South Santiam Watershed:

Table 1. Support Facilities

Facility	Type	Tasks
ISIRF	Federal On-site	Processing & analyzing isotope samples
Tree Ring Laboratory		Analysis of habitat productivity
PEB 114, 115		Processing & analysis of field samples
PEB 118		Staging and storage of field equipment
PEB 119, 108		Sample storage & archiving
EPA Scientific Visualization Center	Federal Off-site	Presentation of model output
Dynamac, Inc.	Non-Federal On-site	Soil GIS database development
Computer Science Corp.		Vegetation GIS database development
Senior Environmental Employment Program		Sample processing / data analysis for model calibration & validation
Oregon Climate Service	Non-Federal Off-site	Climate GIS database development

1. Predict the effect of multiple, interacting stressors on ecosystem biogeochemistry and hydrology.

2. Predict the effect of multiple, interacting stressors on the quality and distribution of wildlife habitat.

3. Predict the effect of multiple, interacting stressors on the movement, distribution and abundance of Western bluebirds and spotted owls.

Our research approach will link models of ecosystem carbon, nitrogen and water dynamics (MBL-GEM) and plant community dynamics (FORCLIM) to predict the effects of multiple stressor scenarios on wildlife habitat quality (plant productivity and nutritional value, species composition, and 3-dimensional vegetation structure). The simulated habitat changes will then be used to drive the PATCH model's projections of spatially and temporally-explicit changes in wildlife populations, initially bluebirds and spotted owls. This work will be accomplished in several steps as follows:

Parameterization and Evaluation of Individual, Unlinked Habitat Models

Our first step in developing an accurate, generally applicable wildlife habitat simulator will be to parameterize and evaluate the individual (unlinked) MBL-GEM and FORCLIM models. The stressor response functions in these component models will be parameterized using stand-level data for a transect of ~1 ha plots located across central Oregon (Table 2). This approximately 200 km transect includes young and old stands (5 to 500+ years in age) at 10 locations extending from coastal rainforests (*Picea sitchensis*, *Tsuga mertensiana*, *Pseudotsuga menziesii*, *Alnus rubra*) to moist west Cascade forests in the USSW (*Pseudotsuga menziesii*, *Tsuga mertensiana*, *Abies* sp.) to semi-arid east Cascade forests (*Pinus ponderosa*, *Juniperus occidentalis*). By encompassing broad, regional-scale differences in climate, soils, vegetation and management practices, the Oregon Transect provides an effective means for constraining model behavior for projected future conditions in the USSW. MBL-GEM will also be parameterized for projected increases in atmospheric CO2, based on data from *Pseudotsuga menziesii* mesocosms exposed to ambient and elevated atmospheric CO2 (Lewis et al. 2001).

The data needed to calibrate the MBL-GEM and FORCLIM models are described in detail in Table 2 and Table 3. These data describe stand-level carbon and nitrogen stocks and fluxes in vegetation and soils, and climatic driving variables (hourly air and soil temperature, precipitation, soil moisture, solar radiation, humidity and wind speed). Similar stand-level data describing an ecologically distinct transect in the Olympic National Park will be used to evaluate the Oregon parameterizations of the individual habitat models. Some of the Oregon and Olympic N.P. data have already been collected under previous EPA projects (Forest Indicators and INFER). The Model Development QATPs for MBL-GEM and FORCLIM describe the procedures for calibrating and implementing these models.

Table 2. Field Sites Used to Parameterize the Habitat Models

Field Site	Physiographic Province	Dominant Tree Species	Annual Precip.	Mean January Temp (Min)	Mean July Temp.
1	Coast Range	Sitka spruce Douglas-fir Red alder	250 cm	2.5 ^oC	20 ^oC
2	Willamette valley	CO2 mesocosms	200 cm	0 ^oC	29 ^oC
3-5, 8	W. Cascade foothills	Douglas-fir W. hemlock	200 cm	-2.5 ^oC	27 ^oC
6, 7	W. High Cascades	True fir sp. Douglas-fir Hemlock sp.	250 cm	-5 ^oC	26 ^oC
9	E. Cascade foothills	Ponderosa pine	40 cm	-9 ^oC	27 ^oC
10	High lava plains	W. juniper	25 cm	-9 ^oC	29 ^oC

Evaluation and Application of the Linked Habitat Models

Our rationale and procedures for linking the biogeochemistry (MBL-GEM) and plant community (FORCLIM) models to establish a comprehensive wildlife habitat simulator is described in the Model Linkages QATP. Maps of current vegetation, soil and climate variables for the USSW will be constructed in a GIS framework to apply and evaluate the linked habitat models. Vegetation maps will be constructed using US Forest Service remote sensing data (Cohen et al. 1995, in press) and US Forest Service stand survey data. The vegetation maps will describe vegetation classes (open, broadleaf, mixed, young conifer, mature conifer and old conifer) at a continuous resolution of 1 hectare. More detailed vegetation properties such as stand biomass, productivity and species composition will be mapped discontinuously with resolution determined by the availability of stand survey data. Soil maps describing key soil drivers for the linked habitat simulator (texture, water holding capacity, and rooting zone carbon and nitrogen stocks) will be constructed for the USSW based on soil samples collected for multiple categories of geomorphic "landtypes" (EPA/US Forest Service Interagency Agreement #DW12938377-02-0). Climate

Table 3. Plant, Soil, and Climate Data

Plant Data	
C & N Stocks	**Methods**
Leaves	Light Extinction
Total Wood	Allometric Relationships (Height & DBH)
Sapwood	Tree Rings
Fine Roots	Soil Cores
C & N Fluxes	**Methods**
Leaf NPP	Litterfall
Wood NPP	Tree Rings
Belowground NPP	Carbon Budget (Raich and Nadelhoffer 1969)
N Uptake & Allocation	^{15}N Labelling

Soil Data	
C & N Stocks	**Methods**
Coarse Detritus	Allometric Relationships
Fine Detritus	Destructive Quadrats
Soil, 0-100cm.	Soil Pits
C & N Fluxes	**Methods**
Soil Respiration	Infared Gas Analysis
N Fixation	Acetylene Reduction
N Mineralization Nitrification	*In Situ* ^{15}N Labelling
N Leaching	Lysimeters

Climate Data	
Above Ground	**Methods**
Air Temperature	
Relative Humidity	
Precipitation	Site-Specific Sensors
PAR	
Wind Speed	
Below Ground	**Methods**
Soil Temperature Soil Moisture	Site-Specific Sensors

drivers for the habitat simulator will be mapped at a resolution of 1 hectare, based on spatial extrapolation of hourly climate data collected for five of our Oregon transect sites located within the USSW. Given grid cell-specific climate and soil drivers and the approximate year of stand initiation as a starting point for simulations, the wildlife habitat simulator will be assessed by how well it predicts current stand and landscape-scale patterns of vegetation structure and function within the USSW. This evaluation will include an uncertainty analysis in which parameters and driving variables are varied within their estimated errors. We will use the verified habitat simulator to generate future vegetation maps for a variety of multiple stressor scenarios. These scenarios will be constructed to test our initial hypotheses about the effects of forest management, climate, CO_2 and nitrogen deposition on spotted owl and bluebird habitats in the USSW.

PATCH Simulations

To apply the habitat simulator predictions to PATCH, projected vegetation classes will be assigned a habitat suitability index of 0-10 for each wildlife species. The indexed habitat data will be used to parameterize PATCH along with data on wildlife survival, reproduction and movement behavior. Thus, for each stressor scenario, PATCH will predict population responses resulting from changes specific to habitat suitability. Comparison of these population responses to different stressor scenarios will be used to test our hypotheses concerning the long-term effects of various stressors on wildlife in this managed forest landscape. The PATCH Model Development QATP describes the procedures for calibrating and implementing the model.

2.2 • Measurement and Data Acquisition

A number of standard operating procedures (Table 4), data collection activities, and data quality objectives (Table 5), will be used to carry out the experimental design described above. Stand-level data will be collected by Project personnel at the field sites listed in Table 2. Landscape-scale GIS databases will be constructed in conjunction with contracts to Dynamac, Computer Science Corporation, and the Oregon Climate Service.

Table 4. Project Tasks, Sorted by SOP

SOP Number	SOP Title	SOP Authors	Location
TH-FL-1-v1	Field Site description for the Terrestrial Habitats Project, Forested Landscape Case Study	R. McKane	Pending
TH-FL-2-v1	Estimation of stand-level leaf area index and leaf biomass	R. McKane C. Wise	Pending
TH-FL-3-v1	Estimation of aboveground biomass components in forest ecosystems	R. McKane	Pending
TH-FL-4-v1	Collection and analysis of litterfall in forest ecosystems	R. McKane	Pending
TH-FL-5-v1	Estimation of wood NPP in forest ecosystems	R. McKane	Pending
TH-FL-6-v1	Estimation of belowground NPP in forest ecosystems	R. McKane	Pending
TH-FL-7-v1	Collection of soil and fine root samples for physical, chemical and biological analyses	M. Johnson	Pending
TH-FL-8-v1	Construction of climate GIS databases for forested landscapes	R. McKane	Pending
TH-FL-9-v1	Construction of soil GIS databases for forested landscapes	M. Johnson	Pending
TH-FL-10-v1	Construction of vegetation and habitat GIS databases for forested landscapes	A. Solomon R. McKane N. Schumaker	Pending
TH-FL-11-v1	Construction of wildlife GIS databases for forested landscapes	N. Schumaker A. Solomon R. McKane	Pending
TH-FL-12-v1 (TERA FOP.01 v1)	Cascade meteorological station operation and data collection	R. Waschmann	Main 255
TH-FL-13-v1 (Forest Indicators SOP)	SOP for spatially mapping trees at forested sites	P. Beedlow	Project Web Site

Table 4. Project Tasks, Sorted by SOP

SOP Number	SOP Title	SOP Authors	Location
TH-FL-14-v1 (Forest Indicators SOP)	SOP for measuring crown diameter	P. Beedlow	Project Web Site
TH-FL-15-v1 (TERA SOP 3.01v1.10)	Carbon/Nitrogen elemental analysis	C. Wise et al.	Main 255
TH-FL-16-v1 (TERA SOP)	Fractionation of forest samples into lignin, cellulose, and extractable components	R. King et al.	Main 255
TH-FL-17-v1 (Forest Indicators SOP)	SOP for measuring tree diameter	P. Beedlow	Project Web Site
TH-FL-18-v1 (Forest Indicators SOP)	SOP for measuring tree height	P. Beedlow	Project Web Site
TH-FL-19-v1 (Forest Indicators SOP)	SOP for measuring water content of wood tissues	P. Beedlow	Project Web Site
TH-FL-20-v1 (Forest Indicators SOP)	SOP for the installation & reading of series 5 manual band dendrometers	J. Greene	Project Web Site
TH-FL-21-v1 (ISIRF EP.07 ver. 1.0)	Tree Core Cutting Methods for Isotope Analysis	Hatfield et al	ISIRF Web Site
TH-FL-22-v1 (INFER SOP)	Tracer methods for quantifying plant nutrient uptake and allocation	R. McKane	Project Web Site
TH-FL-23-v1 (ISIRF OP.07 ver. 1.0)	Finnigan Delta+ IRMS Operation Procedures	W. Griffis	ISIRF Web Site
TH-FL-24-v1 (ISIRF sip/AP.03 ver. 1.01)	Preparation of solid samples for stable isotopic abundance analyses	W. Griffis	ISIRF Web Site
TH-FL-25-v1 (ISIRF sip/EP.03 ver 1.0)	Sample Processing Room Procedures	R. McKane R. Shimabuku	ISIRF Web Site
TH-FL-26-v1 (TERA SOP 3.04 ver 2.0)	Inductively Coupled Plasma – Atomic Emission Spectroscopy	R. King	Main 255
TH-FL-27-v1 (TERA SOP)	*In situ* soil respiration with the Li-Cor 6200	R. Waschmann	Main 255

Table 4. Project Tasks, Sorted by SOP

SOP Number	SOP Title	SOP Authors	Location
TH-FL-28-v1 (TERA SOP 3.03)	Net nitrogen mineralization	E. Govere et al.	Main 255
TH-FL-29-v1 (TERA EP.05 ver 1.0)	Soil solution collection	M. Johnson	Main 255
TH-FL-30-v1 (MDN SOP)	Autoanalyzer methods	J. Compton	Pending
TH-FL-31-v1 (TERA SOP 8.01)	Soil solution carbon analysis	W. Griffis	Main 255
TH-FL-32-v1 (Forest Indicators SOP)	SOP for mapping field sites	P. Beedlow	Project Web Site

3. Quality Assurance and Quality Control

3.1 • Equipment and SOPs

Table 4 lists the SOPs that will be used to ensure quality control and assurance for this case study. These SOPs provide a detailed description of the equipment and procedures for collecting and analyzing the samples and data that support our modeling tasks.

3.2 • Quality Control

Accurate simulation of wildlife habitat and population dynamics by MBL-GEM, FORCLIM and PATCH will require careful collection and analysis of project data. The DQOs and SOPs associated with specific case study data are listed in Table 5. These establish the quality control procedures to ensure that observed habitat and wildlife characteristics are real and not due to bias, sampling error or measurement error. Proper sampling ensures that (1) sample collection procedures yield representative samples of the target, and (2) sample contamination is minimized during collection, handling, transport, preparation, processing, analysis and storage.

To ensure representative and uniform sampling and measurement, all staff involved with sampling and analysis will be required to follow the listed SOPs. Staff will be trained on proper collection, processing and storage of plant, soil, meteorological and wildlife samples and data, as well as data entry procedures and use of equipment. As part of their training, personnel will be given any relevant SOPs and required to follow them for the duration of the project.

3.3 • Quality Assurance

EPA's Quality Assurance Guidelines for Modeling Development and Application Projects (Pilli et al. 1991) define Quality Assurance as "the procedural and operational framework put in place by the organization managing the modeling study to assure technically and scientifically adequate execution of all project tasks included in the study and to assure that all modeling-based analysis is verifiable and defensible." Our QA plans for model development (see Appendices 1, 2 and 3, respectively, for PATCH, GEM and FORCLIM) provide this procedural and operational QA framework.

3.4 • Data Management

A large amount of data will be generated during the course of this study. Raw data will be copied and stored as original field or laboratory notes, and as electronic files with backup copies. Custody of raw data files will be with the Principal Investigators of the Project. For contractor-generated data, a hard copy and electronic copy of all data and calculations will be routed with a summary report to the Work Plan Manager who will in turn send it to the Work Assignment Manager.

Table 5. DQOs and SOPs, Sorted by Project Task

	Description	Expected Range	Accuracy	Precision	SOP Number
Climate Data	Air Temperature	-30 to 40 ^{o}C	±5%	98%	TH-FL-12-v1
	Relative Humidity	1-100%	±5%	98%	TH-FL-12-v1
	Precipitation	50-6000 mm/yr	±5%	98%	TH-FL-12-v1
	PAR	1-3000 umol/m^2/sec	±5%	98%	TH-FL-12-v1
	Wind Speed	0.5-100.0 km/hr	±5%	98%	TH-FL-12-v1
	Soil Temperature	-20 to 35 ^{o}C	±5%	98%	TH-FL-12-v1
	Soil Moisture	1-50% (v/v)	±5%	98%	TH-FL-12-v1
Landscape Scale Data	Climate GIS Database	See Climate Data Units Above	±20% for 1-hectare grid scale	80%	TH-FL-8-v1
	Soils GIS Database	g/m^2 Soil C & N	±20%	80%	TH-FL-9-v1
	Vegetation & Habitat GIS Database	m^2/ha Basal Area	±20%	80%	TH-FL-10-v1
		gC/m^2 Biomass			
	Wildlife GIS Database	Density	±20%	80%	TH-FL-11-v1
		Mortality Rate			
		Reproductive Rate			
Habitat Characteristics	Description of Field Sites	0.1-80.0 m^2/ha (Basal Area)	±5%	95%	TH-FL-1-v1 TH-FL-13-v1 TH-FL-14-v1 TH-FL-17-v1 TH-FL-32-v1
		0.2-1.0 m (Spatial Location)	±25%	90%	
		0.5-1.0 m (Crown Diameter)	±10%	90%	

Table 5. DQOs and SOPs, Sorted by Project Task

	Description	Expected Range	Accuracy	Precision	SOP Number
Soil C & N Fluxes	Soil C & N Chemistry	45-75% C	$\pm$10%	95%	TH-FL-7-v1 TH-FL-15-v1 TH-FL-16-v1
		0.5-4.0% N			
		5-30% Lignin	$\pm$15%	90%	
		40-55% Cellulose			
		10-30% Extractives			
	Soil Respiration	200-1500 gC/m^2/yr	$\pm$20%	90%	TH-FL-27-v1
	Nitrogen Mineralization	1-10 gN/m^2/yr	$\pm$20%	90%	TH-FL-28-v1
	Nitrification	0.8-8.0 gN/m^2/yr	$\pm$20%	90%	TH-FL-28-v1
	Leaching of C & N	0.01-0.50 gN/m^2/yr	$\pm$20%	90%	TH-FL-29-v1 TH-FL-31-v1 TH-FL-30-v1
Plant C & N Fluxes	Leaf NPP	50-200 gC/m^2/yr	$\pm$10%	90%	TH-FL-4-v1
		1-4 gN/m^2/yr			
	Wood NPP	50-600 gC/m^2/yr	$\pm$10%	90%	TH-FL-3-v1 TH-FL-5-v1 TH-FL-21-v1 TH-FL-20-v1
		0.2-2.0 gN/m^2/yr			
	Belowground NPP	100-400 gC/m^2/yr	$\pm$10%	90%	TH-FL-6-v1
		2-5 gN/m^2/yr			
	Nutrient Uptake and Allocation	1-8 gN/m^2/yr (Uptake)	$\pm$10%	90%	TH-FL-22-v1 TH-FL-23-v1 TH-FL-24-v1 TH-FL-25-v1 TH-FL-26-v1
		0.5 – 3.0 gN/m^2/yr (Leaf Allocation)			
		0.2 – 2.0 gN/m^2/yr (Retranslocation)			

Table 5. DQOs and SOPs, Sorted by Project Task

	Description	Expected Range	Accuracy	Precision	SOP Number
Soil C & N Stocks	Forest Floor Detritus	100-10000 gC/m^2 5-200 gN/m^2	±10%	90%	TH-FL-3-v1
	Soil Humus	1000-30000 gC/m^2 100-3000 gN/m^2	±10%	90%	TH-FL-7-v1
Plant C & N Stocks	Tissue C & N Chemistry	40-55% C 0.1-4.0% N 5-30% Lignin 40-55% Cellulose 10-30% Extractives	±10%	95%	TH-FL-15-v1 TH-FL-16-v1
	Leaves	50-600 gC/m^2 1-12 gN/m^2	±10%	90%	TH-FL-2-v1
	Total Wood	500-60000 gC/m^2 2-200 gN/m^2	±10%	90%	TH-FL-3-v1 TH-FL-17-v1 TH-FL-18-v1 TH-FL-19-v1
	Sapwood	400-20000 gC/m^2 1 – 40 gN/m^2	±10%	90%	TH-FL-3-v1
	Fine Roots	100-1000 gC/m^2 2-20 gN/m^2	±10%	90%	TH-FL-7-v1

4. Assessment / Oversight

4.1 • Monitoring

Dr. Robert McKane will provide overall oversight for the Case Study. The principal investigators responsible for each of the primary modeling components will periodically review the status of all datasets and model software for integrity and completeness: Dr. Robert McKane for MBL-GEM;

Dr. Allen Solomon for FORCLIM; and Dr. Nathan Schumaker for PATCH. These reviews will occur both when problems are suspected and in random inspections.

4.2 • Reporting

The primary form of reporting for this project will be manuscripts and reports describing results of investigations. This reporting will include considerations of data quality and model uncertainty discussed in the preceding sections.

4.3 • Model Uncertainty

This section is being prepared by Bob McKane.

5. References

Bugmann, H. K. M. and A. M. Solomon. 1995. The use of a European forest model in North America: A study of ecosystem response to climate gradients. J. Biogeography 22:477 484.

Bugmann, H. K. M. and A. M. Solomon. 2000. Explaining forest composition and biomass across multiple biogeographical regions. Ecol. Applic. 10:95 114.

Cohen WB, Spies TA, Fiorella M (1995). Estimating the age and structure of forests in a multiownership landscape of western Oregon, U.S.A. International Journal of Remote Sensing 16:721-746.

Cohen WB, Maiersperger TK, Spies TA, Oetter DR (2002). Modeling forest cover attributes as continuous variables in a regional context with Thematic Mapper data. International Journal of Remote Sensing (in press).

Lewis JD, Lucash M, Olszyk D, Tingey DT (2001). Seasonal patterns of photosynthesis in Douglas-fir seedlings during the third and fourth year of exposure to elevated carbon dioxide and temperature. Plant Cell Environ. 24:539-548.

McKane RB, Rastetter EB, Melillo JM, Shaver GR, Hopkinson CS, Fernandes DN, Skole DL, Chomentowski WH (1995). Effects of global change on carbon storage in tropical forests of South America. Global Biogeochemical Cycles 9:329-350.

McKane R, Rastetter E, Shaver G, Nadelhoffer K, Giblin A, Laundre J, Chapin F (1997a). Climatic effects on tundra carbon storage inferred from experimental data and a model. Ecology 78:1170-1187.

McKane R, Rastetter E, Shaver G, Nadelhoffer K, Giblin A, Laundre J, Chapin F (1997b). Reconstruction and analysis of historical changes in carbon storage in arctic tundra. Ecology 78:1188-1198.

National Assessment Synthesis Team (2001). Climate Change Impacts on the United States: The Potential Consequences of Climate Variability and Change. Report for the US Global Changes Research Program, Cambridge University Press, Cambridge UK, 620pp.

Pilli, A., R. Erickson, M. Hanratty, J.H. McCormick, J. Nichols, C. Russom, D. Endicott, and J. Westman (EPA Modeling Project Quality Assurance Subcommittee). 1991. Quality Assurance Guidelines for Modeling Development and Application Projects. (http://www.epa.gov/wed/pages/QA/internetpdfqmp.pdf).

Rastetter EB, Ryan MG, Shaver GR, Melillo JM, Nadelhoffer KJ, Hobbie JE, Aber JD (1991). A general biogeochemical model describing the responses of the C and N cycles in terrestrial ecosystems to changes in CO2, climate and N deposition. Tree Physiology 9:101-126.

Rastetter, E. B.and B. L. Kwiatkowski. 2002a. MBL-GEM Model Structure and Equations, Version 6. The Ecosystems Center, Marine Biological Laboratory, Woods Hole, MA 02543.

Rastetter, E. B.and B. L. Kwiatkowski. 2002b. MBL-GEM User’s Manual, Version 6. The Ecosystems Center, Marine Biological Laboratory, Woods Hole, MA 02543.

Appendix 7

Quality Assurance Task Plan for the NESIS Model Development Project

Version 1.3 *August 17, 2005*




1. TASK DESCRIPTION

1.1 • Purpose, objectives, scope

Purpose

The purpose of this task is to develop and apply software for simulating changes in the isotopic signatures of the stocks of elements for which multiple isotopes exist and cycle within ecosystems. The isotope simulator will be used in conjunction with biogeochemical cycling models (e.g., GEM) to better understand the transformations and cycling of natural and experimental isotopes in terrestrial and aquatic habitats. In the context of the Terrestrial Habitats Project, these insights will be used to improve existing models of habitat dynamics to address the following research question: How do multiple, interacting stressors control changes in wildlife habitat and populations across large spatial and temporal scales, i.e., stands to regions and days to centuries?

Objectives

Although isotope-based estimates of process rates have been used to parameterize dynamic simulation models (e.g., Saito et al. 2001), very few ecological models have been developed that simulate the dynamics of isotopes directly (e.g., Currie et al. 1999, Currie and Nadelhoffer 1999, Hobbie et al. 1999, van Dam and van Breemen 1995, Koopmans and van Dam 1998). To incorporate these dynamics in an existing ecosystem model would require a major recoding of the model and would about double its complexity (double the number of state variables). To avoid this recoding, we will develop the Non-Equilibrium, Stable-Isotope Simulator (NESIS) to calculate dynamics in the isotopic signature of an element (e.g., ratio of $^{13}C/^{12}C$). NESIS will do this by using the output from any parent model that predicts the flux rates and stocks of that element for interconnected compartments (e.g., organisms within a food web, or tissues within an organism). Because NESIS operates on the output of the parent model, no recoding of the parent model is required. Our primary objective is to use NESIS in combination with GEM to better constrain and simulate biogeochemical responses to multiple, interacting stressors. Thus, insights gained from NESIS will improve the representation of these responses in comprehensive wildlife assessments.

Scope

The NESIS model will be generally applicable to any model that employs a mass balance approach for simulating gross (rather than net) fluxes of elements among different compartments. This may include models of elemental cycling within and among plants, soils, water bodies, and the atmosphere. Insofar as gross fluxes can be specified, NESIS will simulate the isotopic dynamics (biogeochemical transformations and cycling) of any element having 2 or more stable isotopes, e.g., C, N, O, H, Sr and Rb.

1.2 • Products and Timetable

The primary product of this task will be a generally applicable stable isotope simulator, NESIS, capable of simulating stable isotope dynamics (e.g., ^{12}C and ^{13}C, or ^{14}N and ^{15}N) when used in conjunction with a mass balance model such as GEM. NESIS will be developed during 2003 - 2004. We will initially apply NESIS to GEM in early 2005, following the initial calibration of GEM for the Terrestrial Habitats Project (see QAPP Appendix 2). Our application of NESIS to GEM will use experimental data from field sites in the Cascade Range where stable isotope (^{15}N) experiments have been conducted (see details in INFER SOP "Tracer methods for quantifying plant nutrient uptake and allocation"). Output from the NESIS/GEM simulations will be used to improve the initial calibration of GEM for the goals outlined in the Managed Forest Case Study of the Terrestrial Habitats Project (see QAPP Appendix 6).

1.3 • Project Personnel

Dr. Robert McKane will be responsible for calibrating and validating NESIS and its application to the GEM model. This will include preparing modeling data, conducting simulations, and analyzing and writing up results. EPA scientific staff contributing to the collection and analysis of supporting data include: Dr. Paul Rygiewicz, Dr. Renee Brooks, Dr. Jana Compton, and Dr. Mark Johnson.

1.4 • Support Facilities and Services

Table 1 lists the facilities and services needed to carry out specific tasks that support development of stable isotope data for the application of NESIS. The model will be developed under a contract with scientists at the Marine Biological Laboratory in Woods Hole, MA. EPA-WED laboratory facilities have already been made available and are being used to analyze field samples in support of model calibration and validation. This work will continue through 2007.

Table 1. Support facilities and services for NESIS model development.

Support Facility and Services	Tasks
EPA-WED laboratory facilities	
Integrated Stable Isotope Research Facility	Processing & analyzing isotope samples
Tree Ring Laboratory	Processing of isotope samples
PEB 114, 115	Processing of isotope samples
PEB 118	Staging and storage of field equipment
PEB 119, 108	Sample storage & archiving
The Ecosystems Center, Marine Biological Laboratory, Woods Hole, MA	Formulation and coding of NESIS
Computer Science Corp.	Database development & analysis
Senior Environmental Employment Program (SEE)	Sample processing / data analysis for model calibration & validation

2. Model Description

2.1 • Model Overview

NESIS calculates dynamics in the isotopic signature of the stocks of an element using the output from any parent model that predicts the flux rates and stocks of that element based on a mass-balance approach. Because the NESIS operates on the output of the parent model, no recoding is required. However, all fluxes provided to NESIS must be gross fluxes (net fluxes allow only one-way isotope movement when the movement is actually in two directions). For models based on net fluxes, the model output can often be converted to gross fluxes with a few simple assumptions (e.g., an assumed ratio of net to gross fluxes). To apply the NESIS, the user must also provide the initial isotopic signature for all stocks, the fractionation associated with each flux, and the isotopic signature of any flux originating from outside the system.

2.2 • Model Parameters

The NESIS uses the output of a parent model to approximate separate linear, donor-controlled models for the heavy and light isotope. These models are used to step the isotopic signature of each stock one-time step forward. The parameters in the linear models are then re-estimated for the next time step. To estimate the parameters in these isotope models, a linear, donor-controlled equation is first estimated for each bulk flux that originates from a stock within the modeled system. A detailed description of the component models, parameters, and implementation method is presented in Rastetter et al. (in preparation). A preliminary draft of this document is currently available from Dr. Robert McKane.

2.3 • Computer Aspects

NESIS is written in Delphi 5.0, a Pascal-based programming language developed by Borland. Delphi is object oriented with a native code compiler that runs under Microsoft Windows or Linux-based systems. NESIS is written for Windows systems and can be run using a standard laptop or desktop pc. However, a minimum of 512MB of memory is recommended to reduce simulation time. With this amount of memory the model will require less than 1 minute to simulate isotope dynamics on a daily time-step for 100 years of forest regrowth.

2.4 • Data Sources and Quality

Data on carbon and nitrogen stocks and fluxes that will be used for calibrating, validating and applying NESIS to GEM are described in detail in several QA plans, including the QATPs for the Terrestrial Habitats Project (see appendices for "GEM Model Development," and "Managed Forest Case Study") and the INFER Project (see INFER SOP "Tracer methods for quantifying plant nutrient uptake and allocation"). Those QATP's and the SOPs included therein will establish sampling protocols and procedures for determining the precision, accuracy, representativeness and completeness of the data for this modeling task.

2.5 • Data Management

Datasets will be processed and stored on a Windows pc in the office of Dr. Robert McKane. Backup procedures are those of the standard WED computer backup system.

3. MODEL DEVELOPMENT

3.1 • Code Development and Maintenance

Dr. Edward Rastetter and Bonnie Kwiatkowski of the Marine Biological Laboratory in Woods Hole, MA are writing the program code for NESIS. They will maintain the code and supporting documentation (model structure, parameter definitions, equations and calibration information) on the following website: http://ecosystems.mbl.edu/Research/Models/nesis/welcome.html.

3.2 • Model Documentation

Complete documentation for NESIS is provided in the following document: A Stable Isotope Simulator that Can Be Coupled to Existing Mass-Balance Models, by Edward Rastetter, Bonnie Kwiatkowski and Robert McKane (in preparation). This document is available from Dr. Robert McKane and includes:

- a complete description of the model structure;
- the equations on which the model is based;
- a complete list of variable names and definitions;
- preparing data input files;
- example simulations.

3.3 • Code Verification

The model code has been inspected and tested by the authors with respect to structure, logical errors and internal documentation. However, because NESIS is a new model, verification of the code will be the first priority. Verification of the code will include the use of "virtual" labelling experiments to confirm:

- Conservation of mass of an isotope label added as an initial pulse and subsequently tracked as it cycles through the simulated ecosystem. Thus, the total mass of the isotope label in all pools plus any losses from the system must equal the mass of the initial pulse.
- Accuracy of fractionation constants affecting the rate of transfer of isotopes from one state variable to another.

As the primary "beta tester" of GEM, Dr. Robert McKane will further inspect and verify the NESIS code with respect to its application to GEM. This process will mainly involve exercising

NESIS/GEM against real and theoretical changes in model drivers, state variables and parameters. The objective is to test the models against data for real isotope experiments. Several such experiments have been conducted at EPA-WED field sites by Drs. McKane, Rygiewicz, Compton and Brooks. These data can provide a rigorous test of the isotope simulator against a wide range of isotopes (C, N, O and H) and environmental conditions. If problems are identified in the code, this information will be passed back to the authors, who then correct and document the solutions. All corrections to the model will be followed by a final round of beta testing. A permanent QA record will be maintained for all beta testing procedures and results, including files documenting changes in equations and parameters.

3.4 • Code Documentation

The code for NESIS is publicly available through the website described above (see "Code Development and Maintenance").

4. MODEL APPLICATION

4.1 • Model Calibration

The objective of our calibration procedure will be to derive a parameter set for NESIS that accurately predicts temporal changes in the isotopic signature of experimental systems. This presupposes that the parent model to which NESIS is applied accurately reflects the gross fluxes of the system. In practice, the deviation of simulated from actual isotope data will help guide the implementation of the parent model. That is, an iterative procedure likely will be needed in which the isotope simulations are used to instruct any necessary recalibration of the parent model (e.g., MBL). Thus, parameters in both NESIS and the parent model may need to be iteratively adjusted until an optimal solution is found that accurately reflects the experimental data. This procedure follows the well-established principle that natural and experimental isotopic data provide unparalleled insight into ecological processes.

4.2 • Model Validation

We will validate NESIS by applying the model's parameterization for an initial labelling experiment against other similar experimental data. For example, for the linked NESIS/GEM model, the initial parameterization for one experiment can be validated against other similar experiments, or for subplots within the same experiment that were withheld during the parameterization process. One such opportunity is provided by the tracer experiment described in INFER SOP "Tracer Methods for Quantifying Plant Nutrient Uptake and Allocation." In that experiment ~20 trees were individually labelled with ^{15}N. The allocation of ^{15}N within the tissues individual trees can be simulated by NESIS/GEM and compared on a tree by tree basis. This validation exercise would be important for assessing the models' ability to capture differences in allocation patterns across different tree size classes.

4.3 • Model Uncertainty

Discrepancies between model output and observations may be caused by calibration procedures, specific equations and/or parameters, and data quality. We will quantify model uncertainty for the NESIS/GEM linkage using the same procedures outlined in the Terrestrial Habitats QAPP Appendix 2 (Quality Assurance Task Plan for the GEM Model Development).

5. ASSESSMENT / OVERSIGHT

5.1 • Monitoring

Dr. Robert McKane will provide oversight for the NESIS modeling task. He will periodically review the status of all datasets and model software for integrity and completeness. These reviews will occur both when problems are suspected and in random inspections.

5.2 • Reporting

The primary form of reporting for this project will be manuscripts and reports describing results of investigations. This reporting will include considerations of data quality and model uncertainty discussed in the preceding sections.

6. REFERENCES

Currie, W.S., and K.J. Nadelhoffer. 1999. Dynamic redistribution of isotopically labelled cohorts of nitrogen inputs in two temperate forests. Ecosystems 2:4-18.

Currie, W.S., K.J. Nadelhoffer, and J.D. Aber. 1999. Soil detrital processes controlling the movement of ^{15}N tracers to forest vegetation. Ecological Applications 9:87-102.

Hobbie, E.A., S.A. Macko, and H.H. Shugart. 1999. Interpretation of nitrogen isotope signatures using the NIFTE model. Oecologia. 120:405-415.

Koopmans, C.J., and D. van Dam. 1998. Modelling the impact of lowered atmospheric nitrogen deposition on a nitrogen saturated forest ecosystem. Water, Air, and Soil Pollution 104:181-203.

Rastetter, E.B., B. Kwiatkowski and R.B. McKane. A Stable Isotope Simulator that Can Be Coupled to Existing Mass-Balance Models. In preparation.

Saito, L., B.M. Johnson, J.Bartholow, and R.B. Hanna. 2001. Assessing ecosystem effects of reservoir operations using food web-energy transfer and water quality models. Ecosystems 4:105-125.

Van Dam, D., and N. van Breemen. 1995. NICCCE: a model for cycling of nitrogen and carbon isotopes in coniferous forest ecosystems. Ecological Modeling 79:255-275.